CONTRIBUTION OF *Anabaena circinalis* TO GEOSMIN LEVELS IN LAKE SPAVINAW AND LAKE EUCHA

By

JEANA W. DAVIS

Bachelor of Science

University of Tennessee

Martin, TN

1978

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July 2004

CONTRIBUTION OF *Anabaena circinalis* TO

GEOSMIN LEVELS IN LAKE SPAVINAW

AND LAKE EUCHA

Thesis Approved:

Thesis Advisor

Dean of the Graduate College

ACKNOWLEDGEMENTS

This project was made possible by my co-workers at the city of Tulsa. Many thanks for their time and expertise. The research could not have been done without the many extra analysis they performed. Their willingness to assist made this project feasible.

Many thanks to, Dr. William Clarkson for his guidance, patience and wonderful sense of humor. My appreciation to Dr. Dan Storm and Dr. Ken Ede for their support and direction. Dr Greg Wilber and Dr. Burnap in Stillwater were very helpful with locating chemicals and generous offers of good advice. Dr. Mark Payton's help with statistical analysis on a mere mountain of parameters was greatly appreciated. And thanks to Dr. George Izaguirre, Metropolitan Water District of California, for advice with algal cultures.

I am indebted for the support of family and friends, their support and understanding was and is invaluable.

My admiration goes to Ellen Swallow Richards who planted the seed for ecology. It is over 100 years later and we are still working toward her ideals of clean water, air and food standards

TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION 1

Statement of the Problem 1

II. LITERATURE REVIEW 6

Blooms in Winter Unique 8
Nitrogen 13
Phosphorus 15
Temperature 16
Light 16
Synergistic Effects 18
Hydrologic Impound Factors 21

III. MATERIALS AND METHODS 22

Experimental Conditions 22
Design components 23
Conditions for Experiment 1 25
Conditions for Experiment 2 27
Conditions for Experiment 3 28
Analysis 29

IV. RESULTS AND DISCUSSION 30

Historical Data Review 30
Experimental Results 40

V. CONCLUSIONS AND NEXT STEPS 48

Conclusions 48
Further Research 49

REFERENCES 52

APPENDIX 58

LIST OF TABLES

Table Page

1. Conditions at onset of rise in geosmin levels...20

2. Nutrient levels at the onset of bloom conditions 23

3. Experiment 1 Nutrient values 26

4. Experiment 2 Nutrient values 27

5. Experiment 3 Nutrient values 29

6. Lake Eucha and Lake Spavinaw peak geosmin production......................................40

7. Experiment 1 Results 41

8. Experiment 2 Results 42

9. Experiment 3 Results, Sunlight..43

10. Experiment 3 Results, Limited Light...44

LIST OF FIGURES

Figure Page

1. Eucha Spavinaw Watershed sampling sites 7
2. Microphotograph of *Anabaena circinalis* trichomes 9
3. Microphotograph of *Anabaena circinalis* with heterocysts and akinetes 10
4. Photograph of Experiment 1 in refrigerator 26
5. Graph Eucha Lake geosmin, daylight and water temperature 32
6. Graph Eucha Lake geosmin, ammonia, nitrate, and organic nitrogen 33
7. Graph Eucha Lake geosmin, total and dissolved phosphorus 34
8. Graph Eucha Lake geosmin, chlorophyll-a and N:P Ratio 35
9. Graph Spavinaw Lake geosmin, daylight, and water temperature 36
10. Graph Spavinaw Lake geosmin, ammonia, nitrate and organic nitrogen 37
11. Graph Spavinaw Lake geosmin, total and dissolved phosphorus 38
12. Graph Spavinaw Lake geosmin, chlorophyll-a and N:P Ratio 39
13. Graph of Spavinaw Lake 2003-04 nutrients 46
14. Graph of Eucha Lake 2003-04 nutrients 47

CHAPTER I

Introduction

During recent years, winter-time algae blooms of *Anabaena circinalis* in Lake Spavinaw and Lake Eucha, located in northeastern Oklahoma, have led to periods of increased taste and odor. These lakes are a source of drinking water for the City of Tulsa, Oklahoma and several other communities in Northeastern Oklahoma. Water customers relate taste and odor to water quality. Water with an earthy or musty taste, even if the water meets all water quality standards of the US Environmental Protection Agency (EPA), is not acceptable to today's consumers. Treatment to remove the taste and odor compounds can be expensive; a better alternative is prevention. The goal of this research is to determine conditions that support a fall algae bloom. This will be done at a laboratory scale and by data examination. If a set of circumstances exists that allows the bloom to occur, management practices may allow for prevention. Deterrence of excessive algae growth will be a cost savings for water treatment plants. Taste-free and odor-free water promotes customer satisfaction and consumer confidence. Lake management to deter excess algae promotes a sustained use of a natural resource for wildlife as well as a drinking water source.

Consumers today want drinking water that looks good and tastes good. Objectionable tastes and odors in tap water are among the major complaints recorded by water supply companies. Taste and odor are perceived to be the main reason most consumers switch from tap water to bottled water (Bruchet et al., 1995). Instinctively, the senses of smell and taste serve as an early warning system to protect us against spoiled food, toxins, polluted air and smoke (Bromley, 2000). However, consumers, using taste buds alone, cannot differentiate natural harmless flavors from unhealthy contaminants in water. Naturally occurring flavor nuances in water are caused by minerals, algae, and inherent components of the water. Many of the contaminants regulated in our water systems will have no taste or odor. Bacteria, unless at high concentrations, will be odorless. Lead may be present in water because of older household plumbing using lead solder and will be undetectable by taste (Ternus, 1995). This instinctive reaction to adverse tastes combined with media claims that tap water is unsafe to drink cause consumers to turn to bottled water or home water treatment systems. Public water utilities are required to treat water to meet state regulations and the Federal Safe Drinking Water Act (SDWA). There is mistrust by consumers of "tap" water. Clear, odor-free and taste-free water from public water treatment facilities will help to alleviate some of this mistrust.

Odor in water is regulated under 40 CFR part 143, National Secondary Drinking Water Regulations. These standards address the aesthetic qualities of water and the public acceptance of drinking water. The Secondary maximum contaminant levels are not Federally enforceable but are proposed as guidelines for States. The contaminant level for odor is a Threshold Odor Number (T.O.N.) of 3. The monitoring frequency should be quarterly (USEPA, 2003). Under certain circumstances the monitoring frequency can be reduced. In the event the acceptable level is exceeded, the frequency would increase. The state of Oklahoma places threshold odor under special tests (252:631-3-10(4) (C)) stating that they are required based on local conditions (http://www.deq.state.ok.us/rules/631.pdf.). It is not uncommon for T.O.N. for untreated water to exceed 3, but rarely does treated water in Tulsa exceed this secondary regulation (Source: City of Tulsa).

The Lake Eucha-Spavinaw watershed lies in Northeast Oklahoma and Northwest Arkansas. One of the primary industries in this area is poultry production. Litter from chicken and turkey operations historically has been land applied as fertilizer. Over application has created a situation of excess nutrients entering the watershed through runoff. The poultry industry as well as other point source contributors and several non-point sources have been identified. Runoff is the main mechanism for nitrogen and phosphorus to enter the lakes and create eutrophic conditions (OWRB, 2001).

Tulsa has spent four million dollars in treating the taste and odor problem in the Lake Eucha-Spavinaw watershed (Lassek, 2003). The reported cost for chemicals to treat taste and odor in 1999 was $750,000, tripling treatment costs from prior years (Lassek, 1999). During fiscal year 1998-99, $800,000 was spent on powdered activated carbon at the Mohawk Water Treatment Plant that processes water from Lake Eucha and Lake Spavinaw (Lassek, 2000). These substantial sums were for taste and odor management and are in addition to regular treatment costs.

Tulsa is served by two water treatment plants; A.B. Jewel WTP began processing water from Oologah Lake in 1976. Oologah Lake is managed by the Army Corps of

Engineers and is approximately 30 miles northeast of Tulsa. Unlike the water in Lakes Spavinaw and Eucha, Lake Oologah water has high turbidity resulting in shallow light penetration and in turn a smaller plankton population. This watershed has its own unique problems, but it has not seen the winter algae blooms seen in Lakes Spavinaw and Eucha (www.tulsawater.com).

The blue-green algae blooms which lead to these tastes and odor problems, if left unchecked, could lead to more serious problems. These algae can produce toxins that have serious health effects (Codd, 2000). Evidence suggests that toxic water would be odorous, but not all odorous water is toxic (Bowmer et al., 1992).

The taste and odor episodes in recent years are from the compound geosmin (*trans*-1, 10-dimethyl-*trans*-9 decalol). Geosmin is a known metabolite of several microorganisms including actinomycetes, blue-green algae (cyanobacteria), and some fungi (Lu et al., 2003). It is suspected that the blue-green algal species, e.g. *Anabaena circinalis,* is producing the geosmin and in turn the taste and odor episodes in the Lake Eucha-Spavinaw system. Elevated levels of geosmin have occurred in December 2000 and 2001, but not in 2002. These elevated geosmin levels impart a musty taste and odor to the water. For the purpose of this study, the geosmin level in the lakes was used to define a taste and odor event. Geosmin is often associated with the earthy or musty flavor of red beets (Lu et al., 2003).

These blooms of cyanobacteria (blue-green algae) are a problem in nutrient-rich waters, not only in Oklahoma but also throughout the world. The factors that lead to cyanobacterial blooms have not been satisfactorily identified (Hitzfeld et al., 2000). Contributing factors have been listed as nitrogen, phosphorus, temperature, light, micronutrients such as iron and molybdenum, pH and alkalinity, buoyancy, hydrologic and meteorological conditions as well as morphology of the impoundment. Even though algae are present, they may or may not produce taste and odor compounds. Factors that trigger production of taste-producing substances in the algae have also not been decisively determined (Hitzfeld et al., 2000).

An understanding of the conditions that allow bloom formation can lead to better watershed and lake management. This study will encompass the specific parameters of ammonia-nitrogen, nitrate-nitrogen, organic nitrogen, phosphorus, light and temperature. To determine the effect of these parameters on the growth of *Anabaena circinalis* and the production of geosmin is the goal of this study. Better management may lower treatment costs and satisfy water consumers with odor-free and taste-free water.

CHAPTER II

Literature Review

In the early 1900's Tulsa was a growing town. The large oil reserves found in the area "laid the ground work for cultural and economic developments that exist to this day" (http://www.tulsawater.com). While oil was in abundance, a source for good quality drinking water did not exist in the area. Originally water from the Arkansas River was used for drinking. This water is characterized by a high sediment load, high gypsum and salt contents. In the early 1920's Tulsa purchased land in Spavinaw, Oklahoma. Spavinaw Creek, a crystal clear stream flowing through Ozark wilderness, was dammed to create Spavinaw Lake. Spavinaw Lake has a storage capacity of 39.1 cubic kilometers of water. The water is brought to Tulsa by an 80.5 kilometer pipeline. This most ambitious public works project created the longest U.S. gravity fed pipeline at the time. In 1950 Lake Eucha was created upstream to feed Lake Spavinaw and to provide an environmental and hydrologic buffer. Lake Eucha has a storage capacity of 98.7 cubic kilometers. A second flow line to Tulsa was also added at this time, doubling the water supply to the city. The lakes encompass a 1,074.85 square kilometer drainage basin, 70 percent in Mayes and Delaware counties in Oklahoma and 30 percent in Benton County, Arkansas (Figure 1) (http://www.tulsawater.com).

Approximately half of Tulsa's water is from the Lake Eucha-Spavinaw watershed. The remainder is from Oologah Lake which is fed from the Verdigris River. This water is treated at the A.B. Jewel Water Treatment Plant. Suspended particles are typical in Oologah Lake and allow lesser light penetration. With reduced sunlight, the algae population is smaller than that seen in the Lake Eucha-Spavinaw watershed. The Lake Oologah watershed has its own challenges but typically not taste and odor problems associated with excess algae growth.

As important to this area as oil, clean water is a resource that has made Tulsa the largest city in the area. Clean water is a resource necessary for survival. Clear clean water has been an important part of Tulsa's history. Steps must be taken to preserve the water quality for current and future generations.

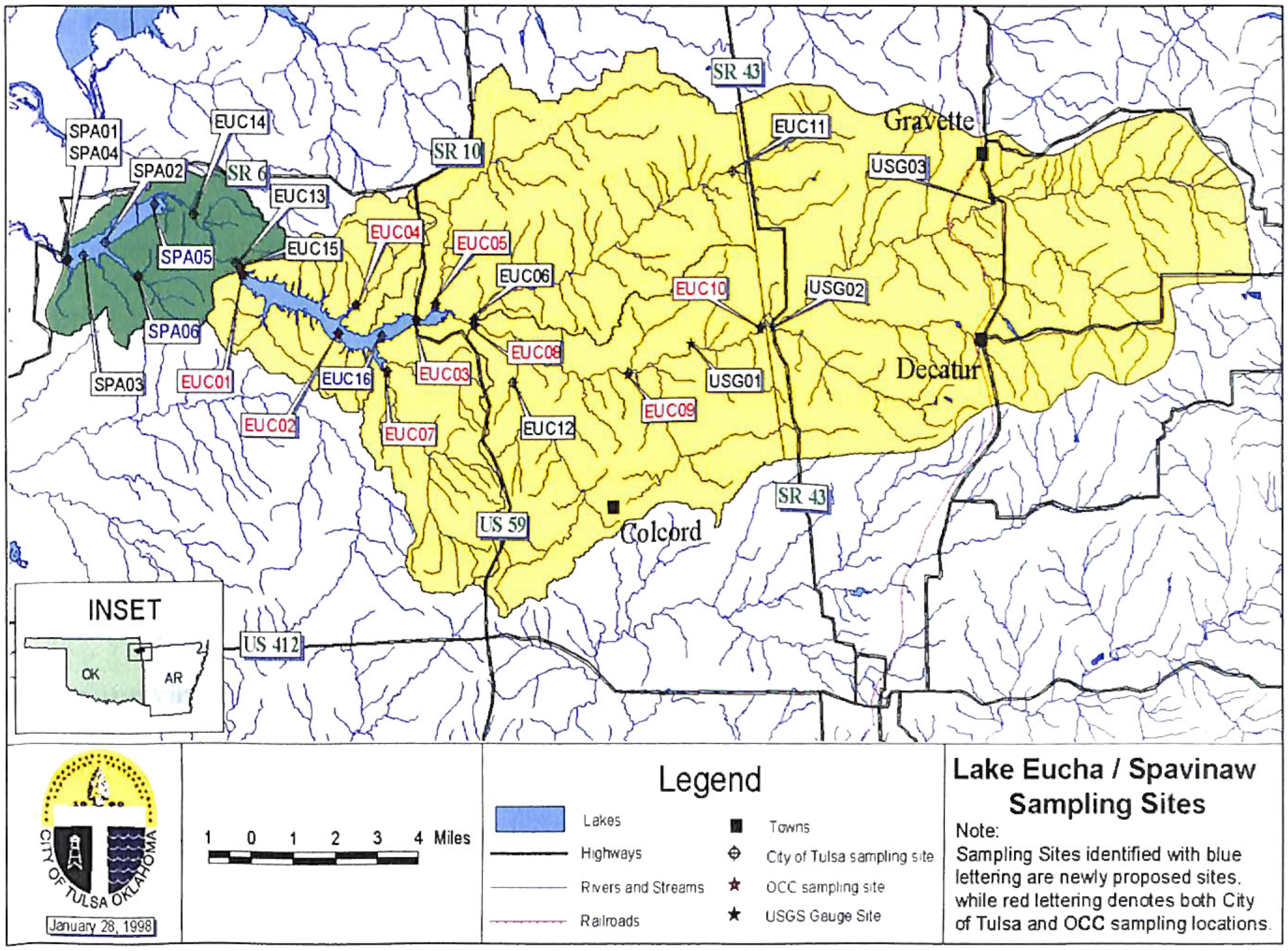

Figure 1. Map of Lake Eucha and Spavinaw watershed and sampling sites. This study uses data and samples from sites: EUC01, Eucha Dam and SPA01, Spavinaw Dam (City of Tulsa Map).

Blooms in Winter Unique

Most blooms of blue-green algae occur in the spring and summer months (Paerl, 1978, Reynolds et al., 2000). Recent blue-green algae blooms in the Lake Eucha-Spavinaw watershed are fall and winter events. During periods of high geosmin levels a surface bloom of *Anabaena circinalis* has been observed (Figure 2). Studies of cyanobacteria in the lakes of the English Lake District noted increases in October and November followed by sharp declines in December (Round, 1961). Conditions that create this shift from summer to fall blooms are outlined in studies done by Horne et al. (1972) on Clear Lake, California. Clear Lake, 185 kilometers north of San Francisco, is a site of autumn blooms of *Anabaena circinalis*. Horne and others defined a specific set of circumstances that lead to an autumn bloom. Most studies focus on the optimum conditions for growth of *Anabaena*, and this study indicated an autumn bloom may be an opportunistic event given that *Anabaena*, because of specific traits of the genus, can survive and thrive when other algal species cannot (Horne et al., 1972). Some *Anabaena* cells can differentiate into heterocysts. Heterocysts are specialized cells that can fix nitrogen (Figure 3). These cells can occur in the presence of low nitrogen concentrations or extreme variations in nitrogen, one trait that may give this species a competitive advantage (Maier et al., 1998).

At Clear Lake, Horne et al.(1972) theorized that the blooms of these nitrogen fixing algae must be associated with more than the nitrogen levels in the lake and must be linked with other limiting chemical factors. In further studies, blooms of *A. circinalis* were found to fix nitrogen when heterocysts were present and there was a low concentration of nitrate and ammonia, high concentration of phosphate and moderately high concentration of dissolved organic nitrogen. In Clear Lake, a eutrophic lake, these conditions occurred in late spring and during autumn overturn. A pattern developed of spring blooms of the cyanobacteria, *Aphanizomenon* and an autumn bloom of *Anabaena* at Clear Lake (Horne et al., 1972).

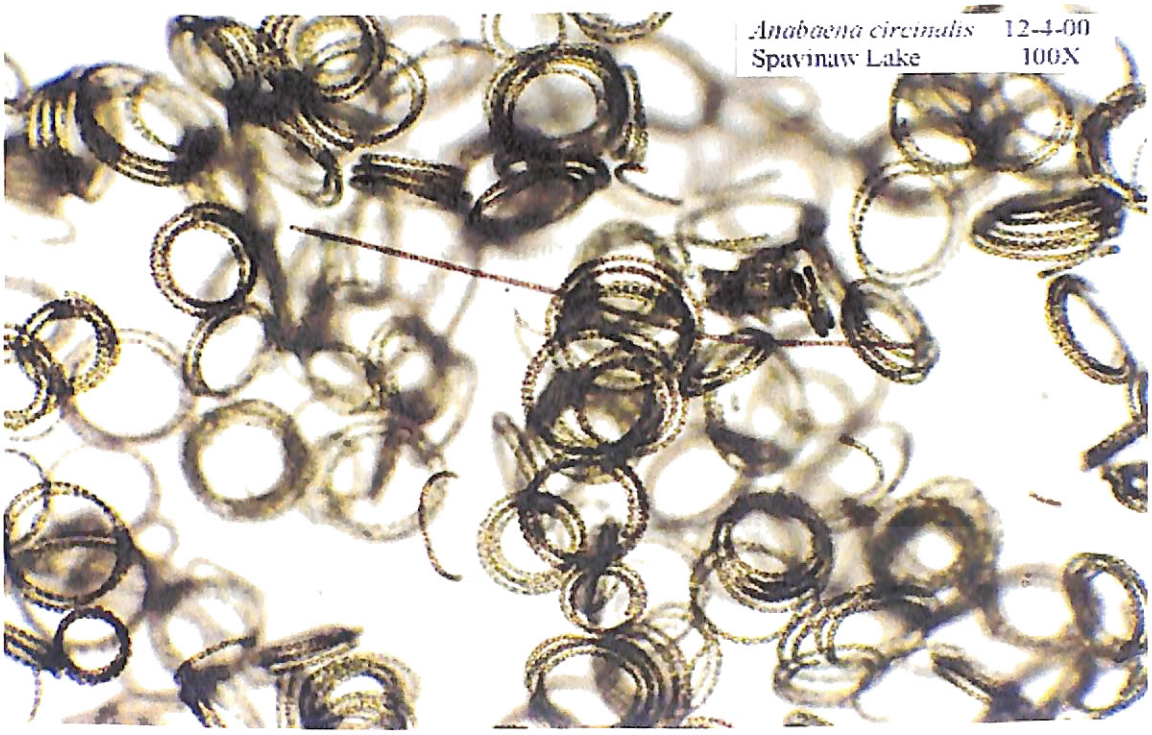

Figure 2. *Anabaena circinalis* trichomes in a typical spiral configuration. Microphotograph taken December 4, 2000. This is a surface grab sample from Spavinaw Lake. The sample was taken during the height of the algae bloom.

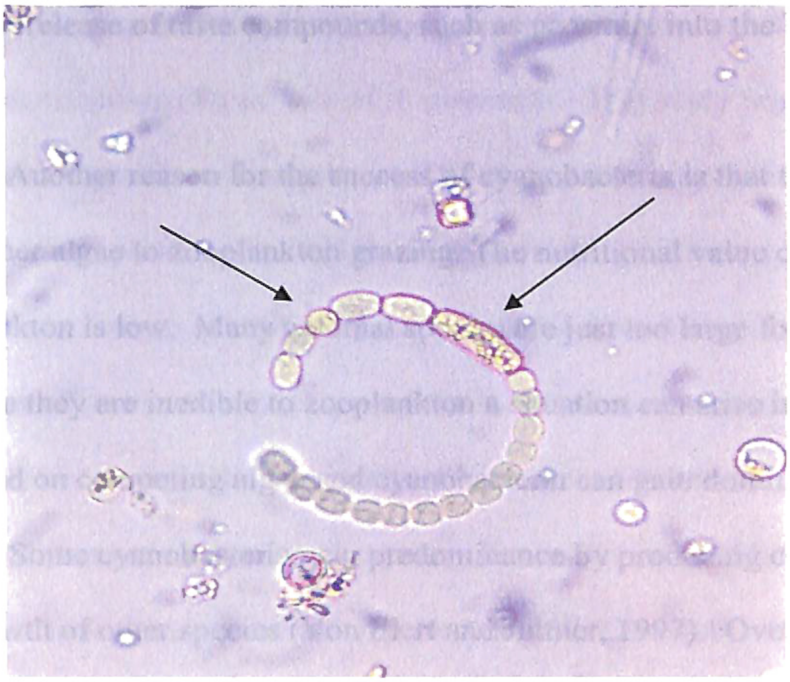

Figure 3. *Anabaena circinalis* trichome (filament) with heterocyst (left) and akinete (right) 320X. A heterocyst is a specialized cell that can fix atmospheric nitrogen. The akinete is a spore-like cell.

Several adaptations make blue-green algae better at utilizing varying light levels. Blue-green algae have a phycobiloprotein group of photosynthetic pigments which absorb higher wavelengths of light than the chlorophylls and carotenoids common to all algae. Blue-green algae can adapt to low light levels, known as shade adaptation. This algal group can produce gas vacuoles that allow cells to change their position in the water column and take advantage of optimum light higher in the water column as well as increased nutrient levels at lower depths (Winder and Cheng, 1995). Thick cyanobacterial blooms may become unable to move and will die at the surface. High light intensity may disrupt this buoyancy regulation. When disrupted, the gas vacuoles remain intact rather than collapsing and allowing the cyanobacteria to sink to lower depths. Wind also helps in the movement, so calm conditions can contribute to cell death and thus release of taste compounds, such as geosmin, into the lake (Graham and Wilcox, 2000).

Another reason for the success of cyanobacteria is that they are less susceptible than other algae to zooplankton grazing. The nutritional value of cyanobacteria to zooplankton is low. Many colonial species are just too large for zooplankton to ingest. Because they are inedible to zooplankton a situation can arise in which the zooplankton will feed on competing algae and cyanobacteria can gain dominance (Gragnani et al., 1999). Some cyanobacteria gain predominance by producing compounds that suppress the growth of other species (Von Elert and Juttner, 1997). Overall, cyanobacteria have several mechanisms that make them adaptable and able to survive and thrive in conditions that are unsuitable for other algal species. Blue green algae can endure, but do not adapt to changes quickly. Cyanobacteria have long lag times in their response to changing conditions and thus are less competitive than other algae that are able to adapt to changes at a faster rate (Winder and Cheng, 1995).

Water in eutrophic lakes is usually stratified into an oxygenated upper level (the epilimnion), a middle layer (the metalimnion), and a non-oxygenated (anoxic) lower level (the hypolimnion). In this anoxic hypolimnion, nitrite (NO_2^-) is converted to ammonium (NH_4^+). This conversion provides a source of nitrogen for plant and algal growth. The supply of phosphorus may exceed the supply of nitrogen in eutrophic lakes. This generates the conditions for a bloom of nitrogen-fixing blue-green algae, such as *Anabaena*. It is common in eutrophic lakes to see strong seasonal differences in chemical and biological conditions (Baker, 1994).

Winder and Cheng (1995) used an algal bioassay technique to determine the optimum conditions for growth of *A. circinalis.* This study began with the premise that blue-green algae blooms are triggered by high water temperature and high phosphorus concentrations combined with low nitrogen to phosphate ratio. The two main objectives of the study were to quantify factors that contribute to blooms and to suggest preventative measures. The bloom enhancing factors included: temperature, light intensity, combined light and temperature, salinity, nutrient concentrations and ratios, silica and particulate matter (tripton). In a laboratory setting, the conditions of 35°C and high light (120 microeinsteins per square meter per second (120μE/m^2/sec)) were determined to be optimum for growth of this species. *Anabaena* was shown to be adaptable to slowly changing salinity concentrations. In these experiments, inhibition did occur at seven percent salinity, but the algae recovered after several days. *Anabaena* was shown to grow at a variety of nitrogen and phosphorus levels and ratios. Perhaps the most significant attribute is that *Anabaena* and other heterocystic blue-green algae can survive and out-compete other algae in low-nitrogen circumstances because they can fix nitrogen.

Silica appears to have a direct inhibitory effect on blue-green algae growth. Silica is a major component in the cell walls of diatoms. Diatoms are the predominant species in colder winter months. High silica levels may increase diatom levels. This is offered as one explanation of why blue-green algae are not usually predominant in the winter. The slower growth rate of blue-green algae at colder temperatures usually allows diatoms to predominate in this niche. The study noted that *A. circinalis* can grow at about one fourth maximum growth capacity at temperatures of 10°C. Experiments to manipulate species domination with silica have yielded unpredictable results. Experiments did show inhibition of *Anabaena* and other blue-green algae using high levels, 5 mg/L of silica (Winder and Cheng, 1995).

Triptonic particles are defined as all particulate matter with the exception of phytoplankton in a water body. Tripton is usually present because of run-off. These particles decrease light penetration and may provide nutrients and silica. While the nutrients are advantageous to all algae the decreased light penetration would be a deterrent to most species, but this generally does not deter *Anabaena* (Winder and Cheng, 1995).

Nitrogen

The important factors to this study are nitrogen, phosphorus, light for photosynthesis, and temperature. Nitrogen and phosphorus cycles play an important part in all algal life. The typical ratio of nitrogen to phosphorus is about 7:1 in all plants and animals. Phosphorus usually is washed from land into a water body. What is not used by the aquatic population is deposited in the sediment. Nitrogen cycling includes a dissolved, sedimentary, and atmospheric phase. In the usually anoxic sediments of lakes, denitrifying bacteria use the oxygen from nitrates to oxidize organic debris. The waste product created in this process is gaseous nitrogen (Volk, 1998). Phytoplankton when growing at their maximum exhibit the characteristic ratio of 106 C:16N:1P, known as the Redfield ratio (Graham and Wilcox, 2000).

In lakes nitrogen and phosphorus are the most important nutrients to blue-green algae growth and the most limiting. In nitrogen-fixing cyanobacteria a low N:P ratio favors bloom conditions. Researchers vary on this limit, but ratios between 29:1 and 22:1 total nitrogen to total phosphorus are documented (Havens et al., 2003). At pH <9 most nitrogen is present as ammonium ion (NH_4^+). This is the most important source of nitrogen for algae, as well as bacteria and other aquatic plants. When the environment does not provide sufficient nitrogen, certain cells will differentiate into heterocysts. Heterocysts reduce atmospheric di-nitrogen to ammonia. These cells differentiate and develop a multilayer cell wall that will provide the micro-aerobic conditions necessary for the nitrogenase enzyme to carry out this chemical reaction (Golden and Yoon, 1998). Figure 2 shows a filament with a heterocyst.

In nitrogen-fixing cyanobacteria, 40-60% of the nitrogen can be released to the open water. This provides nitrogen to other aquatic plants and animals and may balance the dominance or bloom cycle of the cyanobacteria (Graham and Wilcox, 2000). This can be a major input of nitrogen to aquatic ecosystems. This nitrogen production trait is utilized as a source of nitrogen in rice paddy fields in some rice producing countries (Wetzel and Likens, 2000; Sinha and Hader 1996).

Anabaena sp. are nitrogen fixers; environmental levels of ammonium and to a lesser extent nitrate launch the switch to this process (Graham and Wilcox, 2000). They use the enzyme nitrogenase to convert nitrogen gas to ammonium ions which are used directly or converted into nitrate. Because of this unique ability, algae with the potential to fix nitrogen have an advantage in situations of low nitrogen or low nitrogen to phosphorus ratios. Even though nitrogen-fixing algae have an advantage, the metabolic cost is high to the cell. The specialized heterocystic cells are jettisoned from the trichome (colony of cells) when not needed.

Some species of blue-green algae have the ability to form akinetes (See Figure 2). *Anabaena* can form these specialized cells. Akinetes are grown from vegetative cells and function in a similar manner to a spore. These are large, thick-walled cells that are resistant to extremes of temperatures, drying and sunlight. Akinetes have a density higher than water and tend to separate from the trichome and settle down. Akinetes can remain dormant until conditions are again favorable for growth. This contributes to the over-wintering of the algae (Graham and Wilcox, 2000). Cell–to-cell communication using proteins and genes signals certain cells to specialize (Golden and Yoon, 1998). Some research supports low levels of cellular phosphorus as the external trigger for akinete formation (Graham and Wilcox, 2000). Other research indicates low iron levels as inducing akinete production (Hori et al., 2002). Clearly akinetes are a survival mechanism enabling the algae to perpetuate itself beyond periods of environmental stress (Fay, 1988).

Phosphorus

Phytoplankton require only small amounts of phosphorus. Phytoplankton can take advantage of periods of abundant phosphorus and store excess as polyphosphate bodies within the cell, which is termed luxury intake. This stored phosphate can sustain the algae through as many as 20 cell divisions. As indicated by the Redfield ratio, 106C:16N:1P, algal cells only need small amounts of phosphorus (Graham and Wilcox, 2000; Winder and Cheng, 1995).

In lakes phosphorus is typically the least abundant of the necessary nutrients of carbon, nitrogen, phosphorus, oxygen, and sulfur. The phosphorus cycle is complex. Much of the phosphorus is held within the algae cell. Other phosphorus is deposited as sediment and released by decomposition. Because of this, dissolved orthophosphate measurements may not give a good representation of the phosphorus levels in an aquatic system. The largest contribution of phosphorus is from runoff (Wetzel and Likens, 2000).

Temperature

The optimum temperature for cyanobacteria growth is 35°C as determined in lab experiments (Winder and Cheng, 1995). Ambient temperatures would not be in this range so it is not surprising that species can tolerate lower temperatures and flourish at temperatures as low as 15°C (Yoo et al., 1995). Temperatures in the Eucha/Spavinaw Lakes at the onset of an odor event range from 12 to 18°C (City of Tulsa). During an odor event temperatures have historically ranged from 5° to 10°C. Li et al. (1997) report that temperature is a trigger to akinete formation in blue-green algae. It is a logical response to develop an akinete for survival purposes when conditions stress the organism.

Light

In general cyanobacteria can photosynthesize better than other algae under low light conditions because they possess the pigments phycocyanin and phycoerythrin.

These pigments trap red light, which penetrates more deeply in the water column than blue, which is the optimal wavelength for chlorophyll excitation. *Anabaena* is known to do better in low light conditions than other algae. Also high light levels may cause the death of surface blue-green algae blooms (Winder and Cheng, 1995). *Anabaena circinalis* has been shown to adsorb more light in the 400-500nm wavelengths (Agusti and Philips, 1992). In studies by DeNobel and others, *Anabaena* displaced another nitrogen-fixing blue-green, *Aphanizomenon,* when grown together under light-limited conditions (DeNobel et al., 1998).

Cyanobacteria are also able to adjust their position in the water column by filling or emptying vesicles within the gas vacuoles. Under low light conditions the gas vacuoles fill and the cyanobacteria rise to take advantage of higher light levels. This regulation allows cyanobacteria to find the optimum light levels, to have access of nutrients throughout the water column and in bloom conditions to shade the algae below and thus reduce light availability to other species (Yoo et al., 1995; Volk, 1998; Newcombe and Burch, 2003).

Researchers have noted that this rising and falling follows a circadian rhythm. This biological clock is regulated by a genetic oscillator, in which production of a specific protein turns off or on, roughly over a 24-hr period (Barinaga, 1998). This clock offers an explanation of how cyanobacteria can photosynthesize, a process requiring oxygen, and fix nitrogen using a nitrogenase enzyme, which is strongly inhibited by oxygen. These two processes are separated in time and location. Photosynthesis occurs in the upper regions of the epilimnion during the day. Nitrogenase activity occurs at lower depths, with less oxygen during the night. This activity coincides with increased carbohydrate stores during photosynthesis and diminishing stores during the nocturnal nitrogen fixation. Researchers even found this rhythm to persist in situations of continuous light, thus reinforcing the gene-clock theory (Johnson and Golden, 1999).

Synergistic Effects

Rhee and Gotham (1981) studied the combined effects of temperature, light, and day length. Season, latitude and depth will also play an important part in populations of phytoplankton. Their work was done on the green algae *Scenedesmus* and the diatom *Asterionella* and concluded that at lower temperatures, cells require higher levels of nutrients. This may be another factor in creating conditions that favor blue-green algae in eutrophic environments during colder months (Rhee and Gotham, 1981).

Saadoun et al. (2001) linked taste and odor episodes in Lake Ogletree near Auburn, Alabama to *Anabaena* sp. The off-flavor compound produced by the algae was identified as geosmin. In lab experiments, the optimum conditions for geosmin production in *Anabaena* were found to be 20° C with a light intensity of $17\mu E/m^2/s$ (microEinstins per square meter per second). No correlation was found in this study between temperature and geosmin production. It was noted that there is a correlation between temperature and chlorophyll-*a*, in that increasing temperature increased chlorophyll-*a* production and geosmin levels dropped. In a study of *Oscillatoria brevis*, another geosmin producing blue-green algae, Naes and others show an increase of geosmin and chlorophyll at $4.5\mu E/m^2/s$ over cells grown at $30\mu E/m^2/s$. At both light levels chlorophyll and geosmin levels paralleled (Naes et al., 1985). Saadoun et al. note that their research as well as others supports a theory that geosmin and chlorophyll-*a* are produced along the same metabolic pathway (Saadoun et al., 2001; Bowmer et al., 1992). Bowmer et al.'s work suggested that decreasing light intensity causes a cellular shift from chlorophyll-*a* to geosmin synthesis. Because geosmin odor is detectable at very low concentrations, an odor problem can be expected before a bloom is evident. The conclusion of the Lake Ogletree study was that the factor most influencing geosmin production was a low N: P ratio and that neither light intensity nor temperature correlated with geosmin production (Saadoun et al., 2001).

Other elements are needed in small amounts for growth of cyanobacteria and the process of nitrogen fixation. Iron, molybdenum and sulfur are necessary components in nitrogen fixation (Winder and Cheng, 1995,Graham and Wilcox, 2000). Iron is also necessary for cyanobacteria due to its role in many biochemical processes (Maier et al., 1998).

Table 1 outlines the conditions at the onset of increasing geosmin values at the point that geosmin begins to rise above the baseline levels. Water temperatures at Spavinaw and Eucha during high geosmin production ranged from 2 to 18 °C, averaging 11°C. Daylight at this latitude is decreasing from 11 hours in September and October to approximately 10 hours per day for November and December. Samples are taken the first full week of the month. The wide range of values may be attributed in part to this sampling interval. Peak nutrient values may not be represented.

Table 1. Conditions at onset of rise in geosmin levels (+ increasing levels, - decreasing levels, ~ steady levels) based on preceding and succeeding data values. Baseline geosmin is noted as well as the peak measured geosmin for the season. Values are in µg/L unless noted. (Source: City of Tulsa)

	Spavinaw		Spavinaw		Spavinaw		Eucha		Eucha		Eucha	
	2000		2001		2002		2000		2001		2002	
µg/L unless noted												
Baseline geosmin	3 ng/L		5 ng/L		5 ng/L		5 ng/L		14 ng/L		9 ng/L	
Peak geosmin	2600 ng/L		2240ng/L		30 ng/L		34 ng/L		410ng/L		140 ng/L	
Conditions at initial geosmin increase												
Date geosmin above baseline	10/1700		11/17/01		11/25/02		11/15/00		10/16/01		11/14/02	
Ammonia	110	-	220	+	40	+	540	+	300	+	610	+
Nitrate	116	+	110	+	82	+	280	+	190	-	670	-
TKN	1010	-	410	-	440	+	1010	+	630	+	800	+
Organic N*	900	+	190	~	400	+	470	~	330	-	190	-
Total Phosphorus	27	~	31	~	17	~	60	+	25	~	24	~
Day length	11.1	-	10.13	-	10.2	-	10.4	-	11.1	-	10.2	-
Water Temp	18 C	-	17.8 C	-	12.5 C	-	13.6 C	-	17.5 C	-	12.8 C	-
Lake Turnover complete	1-Nov		1-Nov		2-Dec		Nov-00		Nov-01		Nov-02	

*Organic N calculated as TKN value minus ammonia-N value.

Water from Lake Spavinaw flows through the flow line to Yahola Lake, a reservoir for Mohawk Water Treatment Plant (WTP). Changes in treatment are employed when geosmin is present in the source water. Geosmin produced by *Anabaena* is only released upon death of the cell or when the cell is lysed. Treatment schemes that avoid pre-oxidation can remove the algae and its odor compound in the flocculation and sedimentation phase of treatment. Mohawk WTP has granular activated carbon (GAC) filters. These have been shown to remove 80 to 98 percent of the geosmin from the filtered water. If filtered water geosmin levels exceed 10 ng/L, powdered activated carbon (PAC) is added in treatment. A 10 to 15 mg/L dose of PAC can remove 80-90 percent of geosmin present. If this does not provide adequate removal of geosmin an alternate water source is used (Arthur, 2003).

Hydrologic Impound Factors

Lakes Eucha and Spavinaw are stratified eutrophic lakes exhibiting an epilimnion (typically surface to 6 meters), metalimnion, and hypolimnion. The epilimnion in general is well mixed and has the most dissolved oxygen, and is the photic zone for algae growth. The metalimnion represents an often sharp temperature decline. A large algal population may exist at the thermocline because of the density of the colder water. This is especially true if this area is receiving sufficient light for photosynthesis. The colder water will contribute a nutrient supply as it rises from the hypolimnion. The hypolimnion will have the greatest nutrient supply but limited light penetration and low to no dissolved oxygen (Wehr and Sheath, 2003).

Between 38,600 kg and 47,600 kg of phosphorus enters Lake Eucha annually; of this 8,300 kg will flow to Lake Spavinaw while the balance remains in Lake Eucha (Storm et al. 2001). The Oklahoma Water Resources Board (OWRB) has recommended a phosphorus reduction of 70 percent in order to reduce the eutrophication impact on these lakes (OWRB, 2001).

CHAPTER III

Materials and Methods

Experimental Conditions

The scope of this study was limited to the parameters of ammonia, nitrate, organic nitrogen, phosphorus, light exposure, and temperature. Samples from Lake Eucha sample site EUC01 (USG07191285) and Lake Spavinaw sample site SPA01 (USG07191300) (Figure 1) were diluted to adjust nitrate and ammonia values. Solutions were added to bring the organic nitrogen and phosphorus levels to our theoretical bloom conditions. Three experiments were conducted. Water from these sites was used in equal parts for the test solution in experiment 1. For experiment 2 only water from EUC01 was used. In experiment 3 again a mixture was used of equal parts of EUC01 and SPA01.

The bloom conditions were taken from work by Horne et al. (1972) for Clear Lake (California). In the Clear Lake study, blooms occur under specific conditions of low nitrate, high phosphate, moderately high organic nitrogen with *Anabaena* present with heterocysts. The nitrogen fixing ability of *Anabaena* is an advantage in this circumstance. Lake Eucha and Lake Spavinaw exhibit similar conditions to those of Clear Lake; see Table 2 and Figures 5 and 9. The graphs illustrate that organic nitrogen is high with nitrate levels low before increased geosmin levels are observed. One theory is that fall lake turnover provides the necessary "starter" organic nitrogen and other nutrient conditions for an *Anabaena* bloom. These conditions are typical in eutrophic lakes during spring and fall overturn. No specific light or temperature data were given in the Clear Lake study (Horne et al., 1972). Lake Eucha (36.25N) and Lake Spavinaw (36.22N) are geographically close to the same latitude as Clear Lake (38.97N) so natural light values are similar. Temperatures typical of Oklahoma lakes were used in the experiments. Three phosphorus levels were used. Light and temperatures varied as indicated in each experiment. All other parameters were constant.

Table 2. Comparison of nutrient values at the onset of bloom conditions in Clear Lake and Lakes Eucha and Spavinaw. Both lakes experience a fall de-stratification or turnover that contributes to changes in nutrient values.

Nutrient Levels at the onset of Bloom Conditions		
Nutrient	**Clear Lake**	**Eucha & Spavinaw Lakes**
Ammonia-N	<10-440 μg/L	<40-610 μg/L
Nitrate-N	14-160 μg/L	82-670 μg/L
Organic-N	525 μg/L	190-900 μg/L
Phosphorus-P	17-360 μg/L	17- 60 μg/L

Design Components

The experiments were set up using 1-liter clear plastic flasks. A hole was drilled in the top of each flask to allow tubing with an air stone to be inserted. The tubing was connected to an aquarium pump to provide aeration and a positive pressure to each flask. A 0.45μm filter was placed in the air line between pump and flasks to trap any bacteria. The wide spectrum light was connected to a timer in order to control the amount of light. Experiment 1 was conducted at 15°C; a refrigerator provided the (see Figure 12) temperature controlled environment. All other experiments were set up the same and done at indoor room temperatures.

1) 6-sterilized 1-L clear plastic bottles, each P concentration in duplicate
2) Air pump- to provide a constant DO
3) GE-wide spectrum plant/aquarium fluorescent light, 15W
4) 0.45μm syringe filter on each air line to provide bacteria-free air
5) Air stones, to diffuse air
6) Tubing
7) Multiport manifold
8) Timer –for light- set to turn on at 8am and off at 6 pm
9) Refrigerator set between 11-14°C

1. Steps to get the lake water to the desired experimental levels:

    a. Experiment 1: Equal portions of Lake Eucha (EUC01) and Lake Spavinaw (SPA01) samples were filtered through a 125-micron mesh screen to remove any zooplankton and reduce grazing by the zooplankton on our subject algae. A 4-mL concentrate from Lake Yahola was added to provide *Anabaena circinalis.*

    b. Experiment 2: Lake Eucha sample was used. The sample was not filtered, because it was learned most zooplankton do not feed on blue-green algae. This would eliminate a possible source of contamination. *Anabaena circinalis* was present in the sample so no other source was provided.

    c. Experiment 3: Lakes Eucha and Spavinaw samples were used in equal portions. Samples were not filtered. Some *Anabaena* circinalis were present. A 100µL portion of *Anabaena circinalis*, taken from the bloom in progress at Spavinaw was added to each sample and control.

2. For all three experiments 200 mL of a combination of water from Lake Eucha (EUC01) and Lake Spavinaw (SPA01)was placed into a 2-L volumetric flask. A 1:10 dilution was necessary to get the ammonia-nitrogen in the appropriate range.

3. To adjust organic nitrogen to desired experimental level of 500 µg/L an appropriate amount of an EDTA solution containing 1000 mg/L of nitrogen was added.

4. To adjust phosphorus levels add the appropriate amount of a potassium phosphate solution containing 1000 mg/L of phosphate for a final concentration of 20 µg/L, 200 µg/L and 400 µg/L of phosphate. Bring to a final volume of 2 liters using Type I water.

5. Samples at each phosphorus level were prepared in duplicate. The adjusted water is poured into 2-1 liter plastic bottles. An air-stone was attached to plastic tubing that is threaded through a hole in the cap of the bottle. The tubing was connected to the air pump to provide a saturated DO level. The air leaving the pump passes through a 0.45µm filter to filter out any bacteria. This air flow also creates a positive pressure to keep airborne bacteria from entering the bottle.

Reagents

1. Phosphorus solutions 1000 mg/L - Weigh 4.39 g KH_2PO_4 bring to 1-liter final volume. (Formula weight KH_2PO_4=136, weight phosphorus =31, 31/136 = 0.228. 1g/0.228 = 4.39g)

2. Organic nitrogen solution 1000 mg/L nitrogen EDTA, disodium salt- Weigh 12.14 g $C_{10}H_{14}N_2Na_2O_6.2H_2O$ bring to 1-liter final volume. (Formula weight = 340, weight of N = 28, 28/340 = 0.0824, 1g/0.0824 = 12.14g)

3. Reagent grade, Type I water- Deionized water of at least 18megohm, filtered through 0.2 micron filter and UV disinfected.

Light values were calculated from factors for a 15 watt, GE wide spectrum plant and aquarium grow light. 15 watts x 0.943= 14 μE (Busko, 2004). One microeinstien (μE) is equal to 6.02×10^{17} photons. Direct sunlight is estimated to be approximately 2000μE (Gagliardi and Stiff, 2003). Windowsill experiments were estimated to be in the region of 200 $\mu E/m^2/s$.

Conditions for Experiment 1

Using Lakes Eucha and Spavinaw water collected in the September 8, 2003 sampling, the original nutrient values were: NH_4-N 338 μg/L, NO_3-N <35 μg/L, Organic Nitrogen (TKN-NH_4) 466 μg/L, total phosphorus 117μg/L, and dissolved phosphorus 61 μg/L. The geosmin level was 3.2 ng/L. Microscopic examination confirmed that *Anabaena circinalis* were present with heterocysts. These parameters were adjusted as shown in Table 3.

Table 3. Experiment 1. Samples were diluted then spiked with PO_4-P and Organic-N to adjusted levels. The original value is shown, diluted values, adjusted value and the amount of spike added for adjustment is in the last column.

Experiment 1 Lakes Eucha/Spavinaw	Original Value	100mL Sample to 900 DI[1] Water	Amount of solution added per liter	Adjusted values	Addition Per 2 L
9/8/2003					
NH_4-N	338μg/L	33.8μg/L	0	33.8μg/L	0
NO_3-N	<35μg/L	<35μg/L	0	<35μg/L	0
Soluble [2]			450μl of		900 μL
Organic N	466μg/L	46.6μg/L	1000mg/L	500	
			10μL	20	20μL
Soluble			190μL	200	380μL
PO_4-P	TP[3]=117μg/L	11.7μg/L	390μL	400	780μL
	DP[4]=61μg/L				
Total Fe	NA				

1. DI= Deionized Water
2. Soluble organic nitrogen values are total kjeldahl nitrogen, TKN, minus ammonia nitrogen values.
3. TP= Total Phosphorus
4. DP= Dissolved Phosphorus

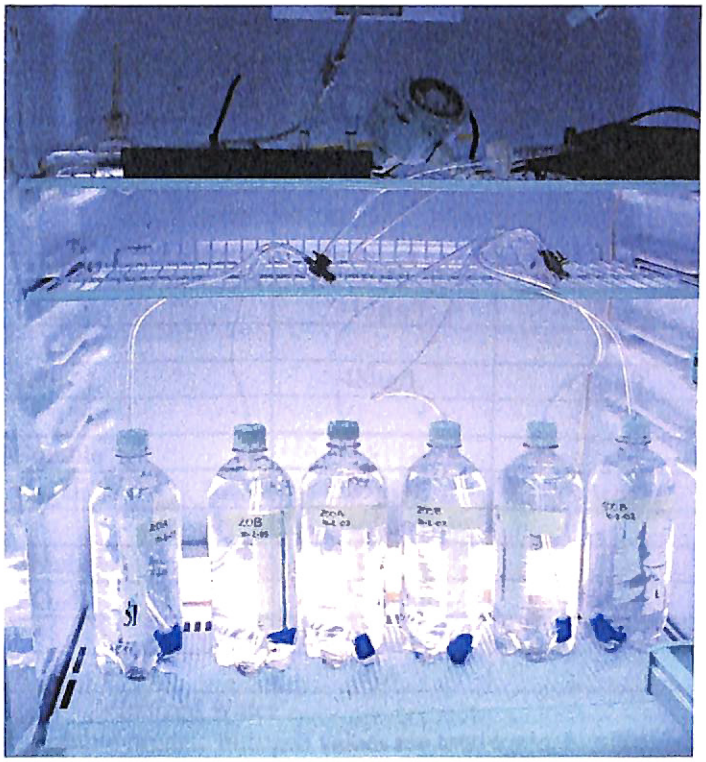

Figure 4. Photograph of Experiment 1. A refrigerator provided the 15°C environment. The wide spectrum grow light provides low light from 8am until 6pm each day. An aquarium pump provided constant dissolved oxygen and a positive pressure to each flask.

Experiment 1 was placed in a refrigerator; the temperature was adjusted to 15°C. Light at approximately 14 $\mu E/m^2/s$, was timed to begin at 8am and end at 6 pm each day (Figure 4). Plankton was counted and geosmin was measured on day 13, 27, and 39.

Conditions for experiment 2

Using Lakes Eucha and Spavinaw water collected in the October 6, 2003 sampling of Eucha Dam (EUC01), the original values were: NH_4-N 413 µg/L, NO_3-N 48 µg/L, Organic Nitrogen (TKN-NH_4) 585 µg/L, total phosphorus 48µg/L, and dissolved phosphorus 38 µg/L. Geosmin level was 3.2 ng/L. *Anabaena circinalis* were present with heterocysts. These parameters were adjusted as shown in Table 4.

Table 4. Experiment 2. Samples were diluted then spiked with PO_4-P and Organic-N to adjusted value levels. The original value is shown, diluted values, adjusted value and the amount of spike added for adjustment is in the last column.

Experiment 2 Lakes Eucha/Spavinaw	Original Value	100mL Sample to 900 DI[1] Water	Amount of solution added per liter	Adjusted values	Addition Per 2 L
10/6/2003					
NH_4-N	413µg/L	41.3µg/L	0	41.3µg/L	0
NO_3-N	48µg/L	4.8µg/L	0	4.8µg/L	0
Soluble [2]			440µL of		880µL
Organic N	585µg/L	58.5µg/L	1000mg/L	500	
			15µL	20	30µL
Soluble			195µL	200	390µL
PO_4-P	TP[3]=48µg/L	4.8µg/L	395µL	400	790µL
	DP[4]=38.5µg/L				
Total Fe	NA				

1. DI= Deionized Water
2. Soluble organic nitrogen values are total kjeldahl nitrogen, TKN, minus ammonia nitrogen values.
3. TP= Total Phosphorus
4. DP= Dissolved Phosphorus

Experiment 2 was placed in a window with a southern exposure and kept at room temperatures which fluctuated between 15-25°C. The wide-spectrum grow-light was illuminated 10 hours each day, from 8 am to 6 pm. This experiment took advantage of natural sunlight and day-length for November, December, and January- the season when this phenomenon has occurred in the lakes.

Conditions for experiment 3

Lakes Eucha and Spavinaw samples collected January 4, 2004 were used in equal portions. Original values were: NH_4-N 240 μg/L, NO_3-N 196 μg/L, Organic Nitrogen (TKN-NH_4) 136 μg/L, total phosphorus 21μg/L, and dissolved phosphorus <5 μg/L. Geosmin level was 68.9 ng/L. *Anabaena circinalis* were present. These parameters were adjusted as shown in Table 5.

Experiment 3 consisted of two identical sets of samples, again with phosphorus levels of 20, 200 and 400 μg/L and a control. Set 1 was placed in the southern exposure window, the same site as experiment 2. Set 2 was placed in the same room but covered to limit illumination to the wide-spectrum grow light at approximately 14 $\mu E/m^2/s$, as in experiment 1. Temperature for each set should be very similar. Radiant heat from solar exposure may increase the temperature of set 1 in the windowsill. The goal is to determine the effect light has on the production of geosmin. Experiment 1 produced geosmin with reduced light and low temperatures. One variable is eliminated to determine if light or temperature alone is the contributing factor in this phenomenon.

Table 5. Experiment 3. Samples were diluted then spiked with PO_4-P and Organic-N to adjusted value levels. The original value is shown, diluted values, adjusted value and the amount of spike added for adjustment is in the last column

Experiment 3 Lakes Eucha/Spavinaw	Original Value	100mL Sample to 900 DI[1] Water	Amount of solution added per liter	Adjusted values	Addition Per 2 L
1/5/2004					
NH_4-N	240µg/L	24µg/L	0	24µg/L	0
NO_3-N	196µg/L	19.6µg/L	0	19.6µg/L	0
Soluble [2]	136µg/L	13.6µg/L	450µL of		
Organic N			1000mg/L	464µg/L	900µL
Soluble			20µg/L	20µg/L	40µg/L
PO_4-P	TP[3]=21µg/L	2.1µg/L	200µg/L	200µg/L	400µg/L
	DP[4]=BDL(5) µg/L		400µg/L	400µg/L	800µg/L
Total Fe	NA				

1. DI= Deionized Water
2. Soluble organic nitrogen values are total kjeldahl nitrogen, TKN, minus ammonia nitrogen values.
3. TP= Total Phosphorus
4. DP= Dissolved Phosphorus

Analysis

Geosmin and 2-Methylisoborneo (MIB), another common taste and odor compound from algae, were measured by Standard Method 6040-D using solid phase microextraction (SPME) and GC/MS analysis. Plankton was counted using Standard Method 10200-F using a Sedgwich-Rafter (S-R) cell and microscope equipped with a Whipple grid. Nutrient analyses were performed with a Lachat QuickChem 9000 automated analyzer. These EPA methods were utilized: Nitrate/Nitrite-EPA 353.2, Ammonia-EPA 350.1, TKN-EPA 351.2, Phosphorus-EPA 365.4 and 365.1, Orthophosphate-EPA 365.2. Chlorophyll-*a* analysis was done using Standard Methods 10200-H.

CHAPTER IV

Results and Discussion

Historical Data Review

Samples taken by City of Tulsa personnel and analysis generated by the City of Tulsa, Quality Assurance Laboratory were used in this review. The initial data review consisted of data beginning in August 1999 through March of 2003. No geosmin data were available for these lakes prior to this date. Data generated in fall of 2003 and spring of 2004 were reviewed concurrently with the experiments.

The highest levels of geosmin in Lakes Eucha and Spavinaw occur in the winter months. Lake Eucha geosmin is compared with other lake conditions on Figures 5, 6, 7 and 8. Lake Spavinaw geosmin compared with other lake conditions are displayed on Figures 9, 10, 11 and 12. In general, nutrient sampling was performed monthly and geosmin sampling weekly. Table 6 summarizes the initial geosmin rise, high points and the return to baseline geosmin levels. Historically Lake Spavinaw has produced the highest levels of geosmin. The highest recorded geosmin value to date is 2600 nanograms per liter (ng/L) in December 2000. To put this in perspective, people can detect the taste and odor of geosmin in the range of 4 to 10 ng/L (Watson et al., 2000).

Figure 2 is a microphotograph of a grab sample of surface water from Spavinaw Lake at peak geosmin levels. This is not a concentrated sample. The lake biologist noted that this formed a surface plankton layer moved by wind and currents into coves and shoreline. Geosmin odor was very prevalent in the sample. Typical plankton sampling employed at the lakes is a composite from the water column. This may explain why samples did not show an accurate accounting of the *Anabaena* present in the lakes.

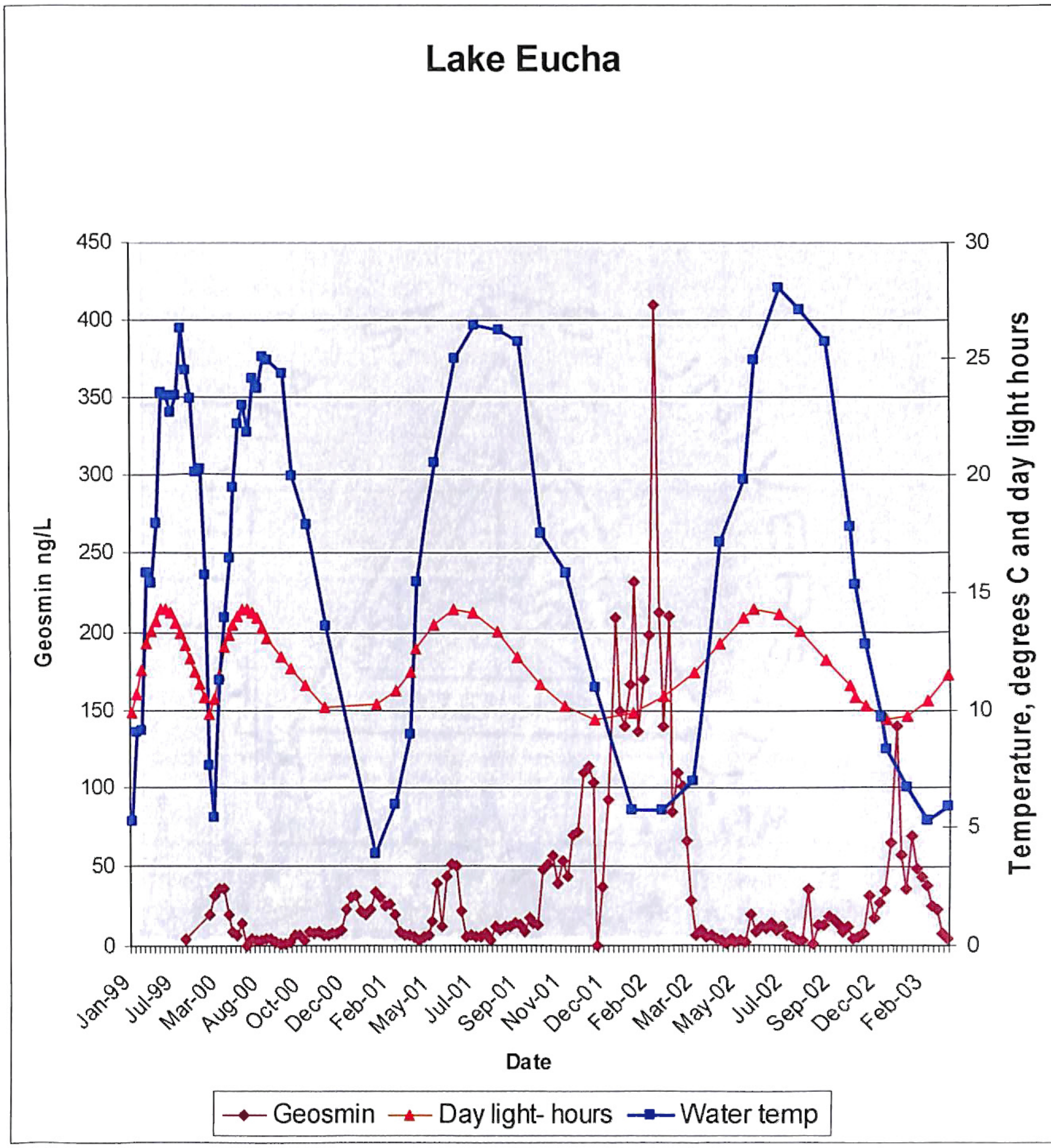

Figure 5. Lake Eucha geosmin values, left scale are compared to water temperature and Day light in hours, right scale. Note the largest geosmin peak in winter of 2002, during the coldest and darkest portion of the year (Source: City of Tulsa).

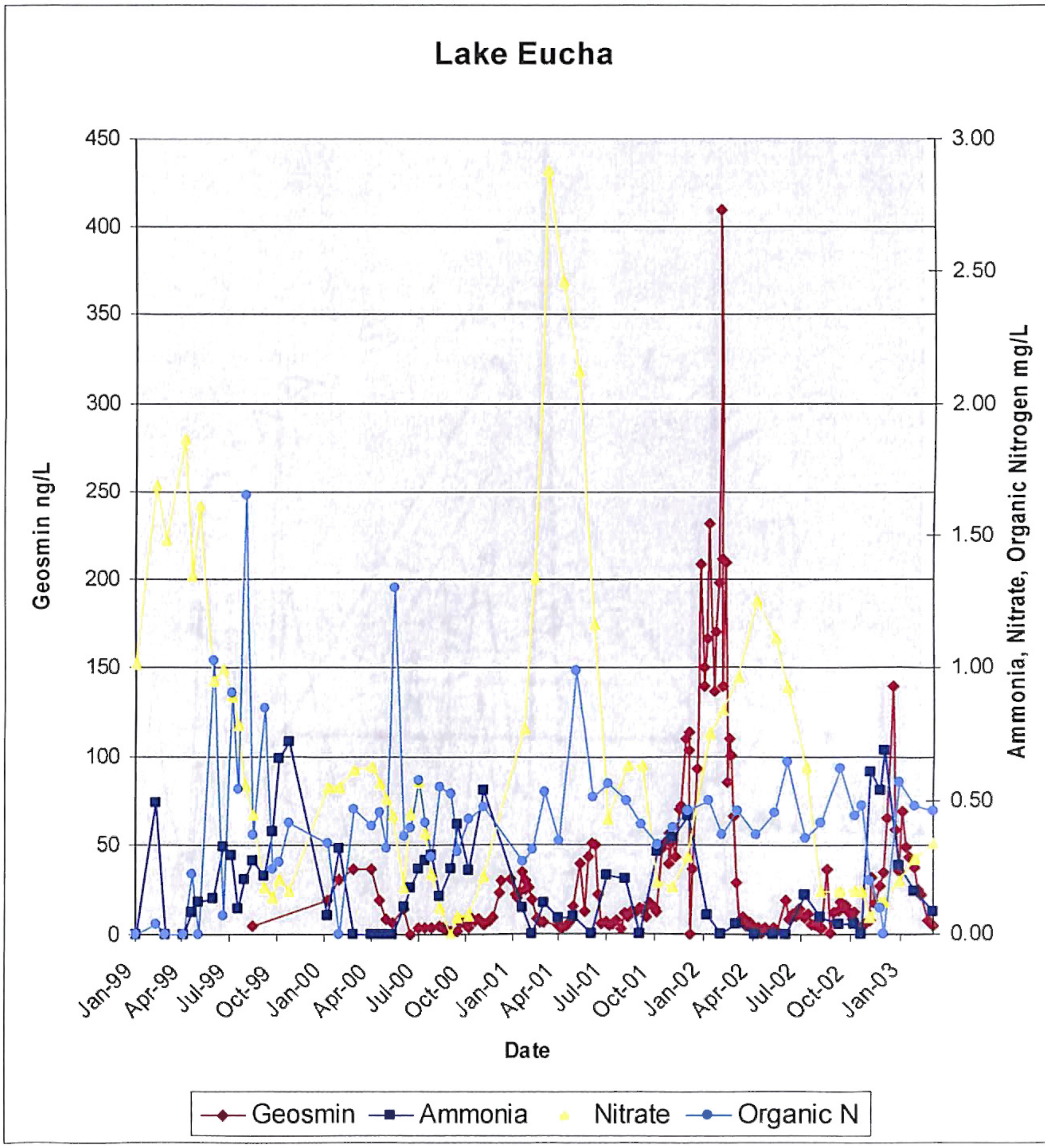

Figure 6. Lake Eucha geosmin values, left scale are compared to ammonia-N, nitrate-N and organic nitrogen, right scale. Note the dip in nitrate-N and rise in ammonia-N preceding an increase in geosmin (Source: City of Tulsa).

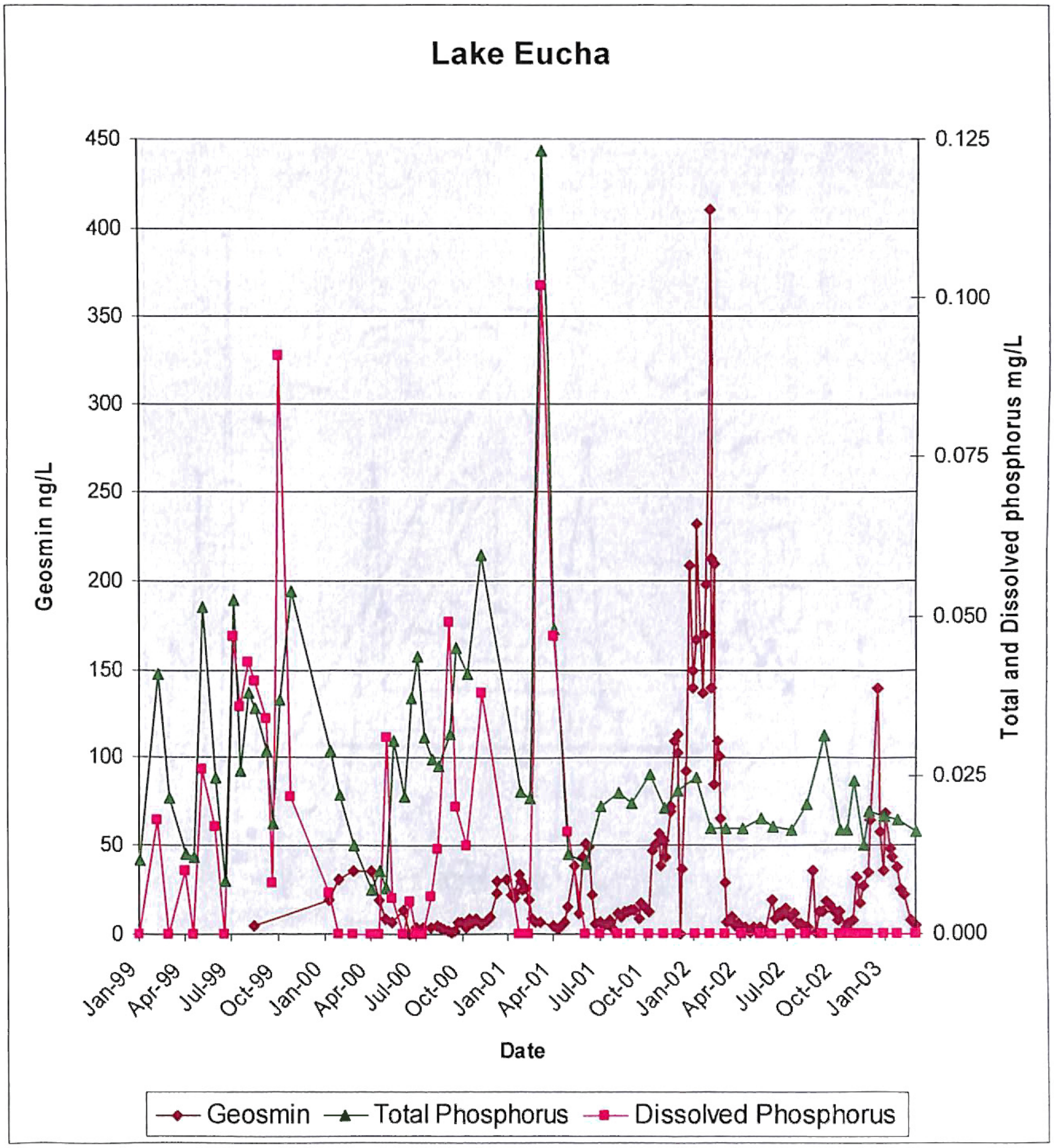

Figure 7. Lake Eucha geosmin values, left scale, compared to total and dissolved phosphorus, right scale. Total phosphorus fluctuates but the average value for these years is 0.03 mg/L (Source: City of Tulsa).

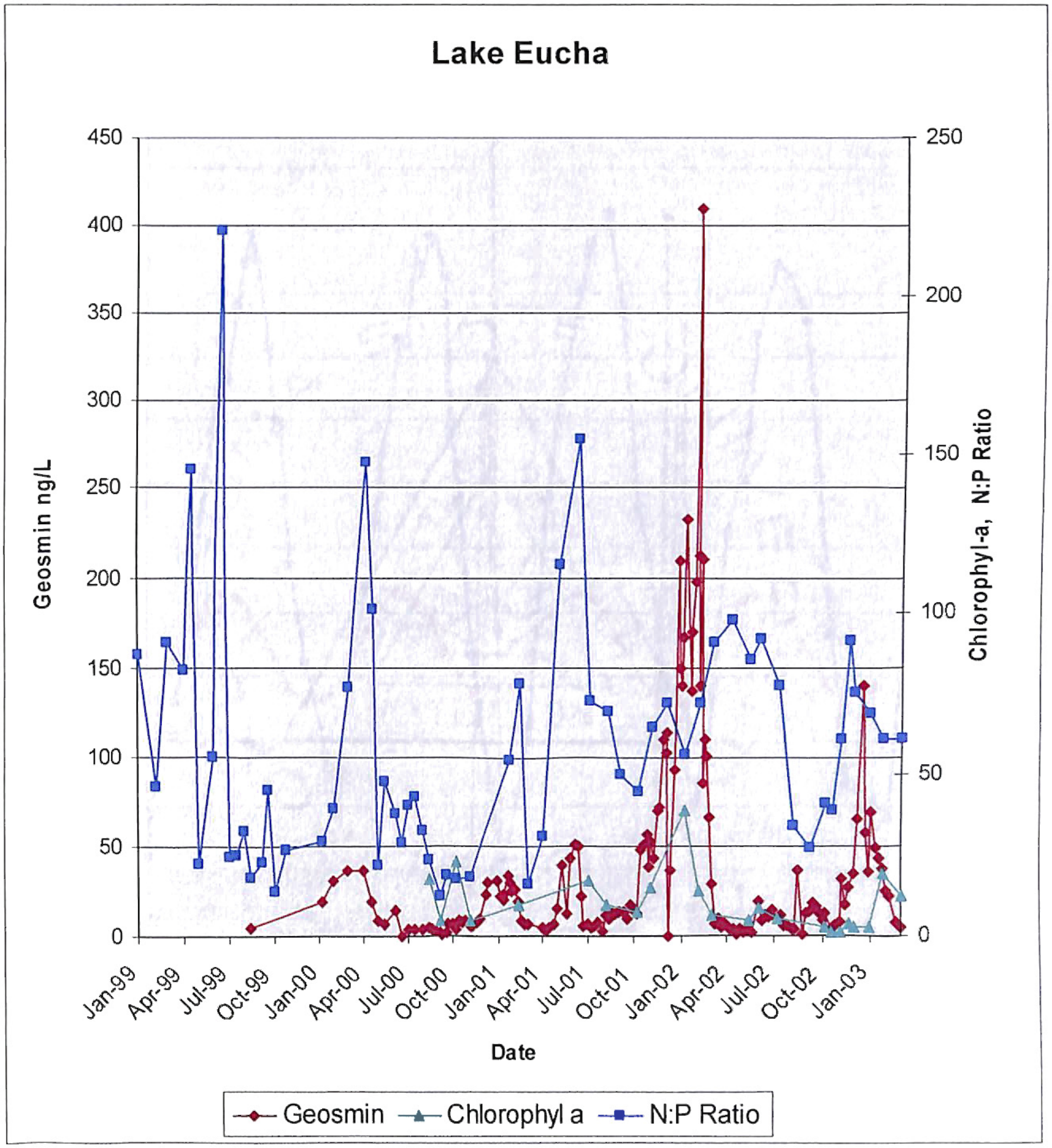

Figure 8. Lake Eucha geosmin values, left scale, compared to the N:P ratio and chlorophyll-*a*, right scale. Note the lower N:P ratio before a rise in geosmin (Source: City of Tulsa).

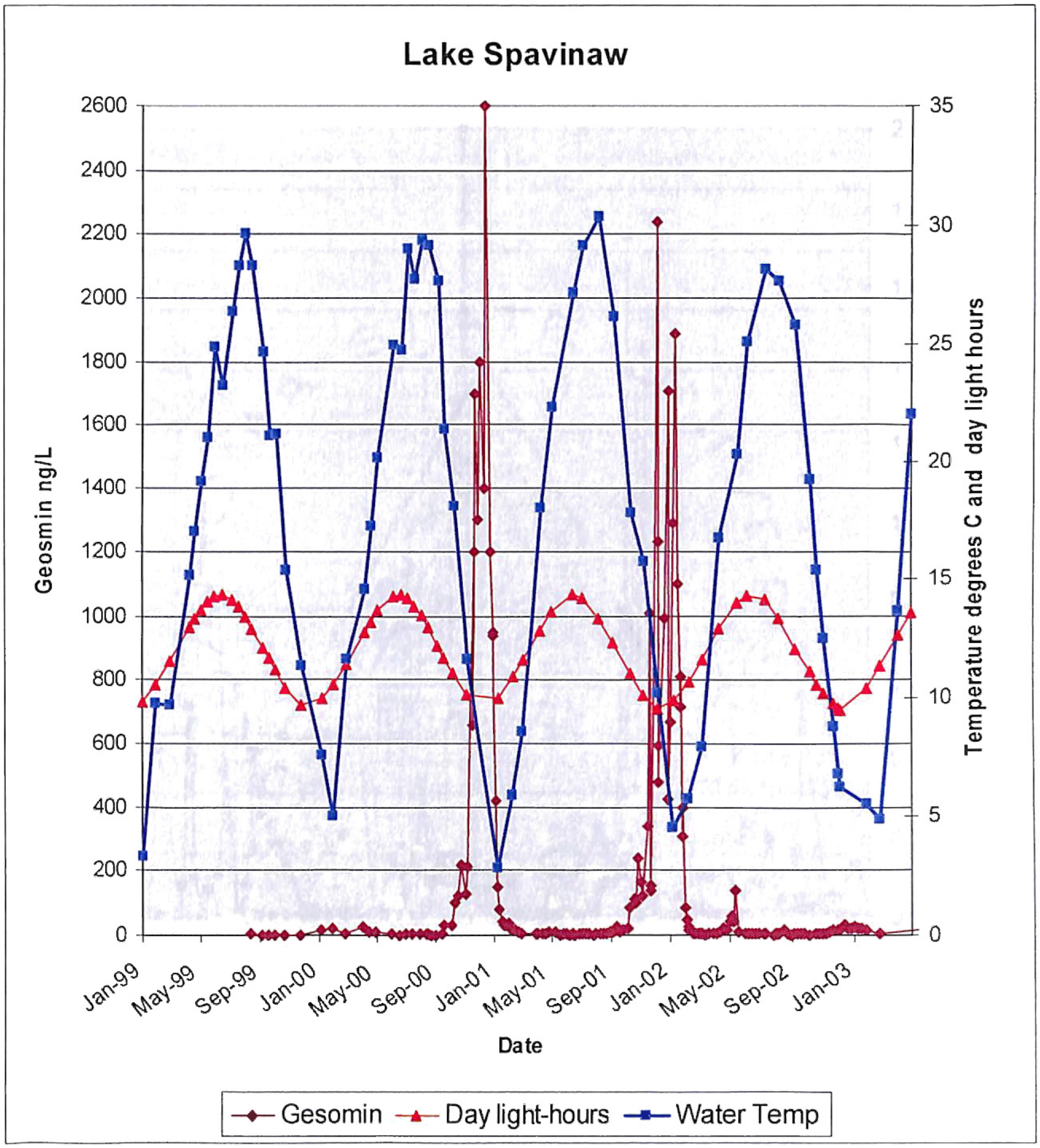

Figure 9. Lake Spavinaw geosmin values, left scale are compared to water temperature and daylight hours, right scale. Note the largest geosmin peak in winter of 2002, during the coldest and darkest portion of the year (Source: City of Tulsa).

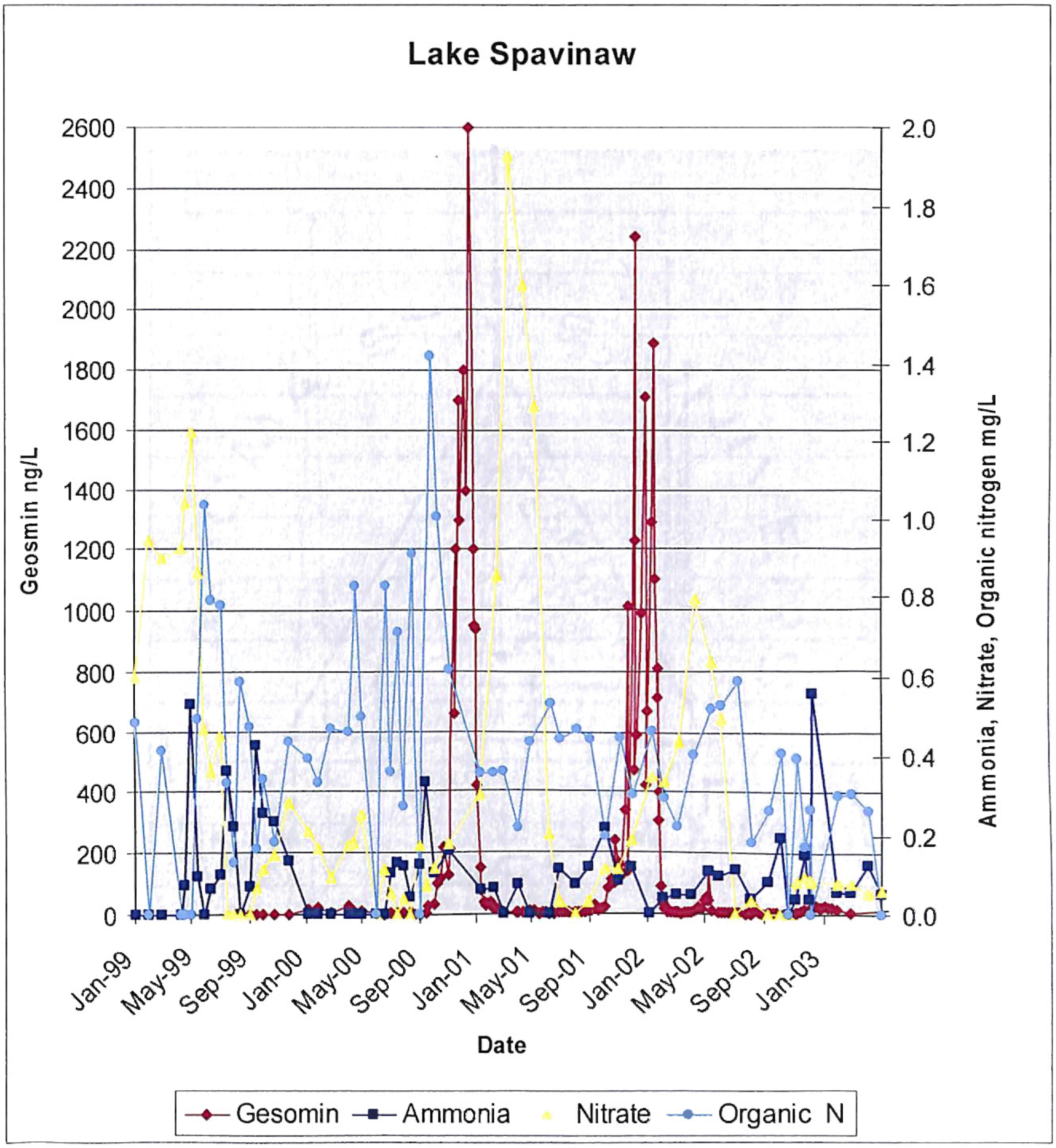

Figure 10. Lake Spavinaw geosmin values, left scale are compared to ammonia-N, nitrate-N and organic nitrogen, values right scale. Note the dip in nitrate-N and rise in ammonia-N preceding an increase in geosmin (Source: City of Tulsa).

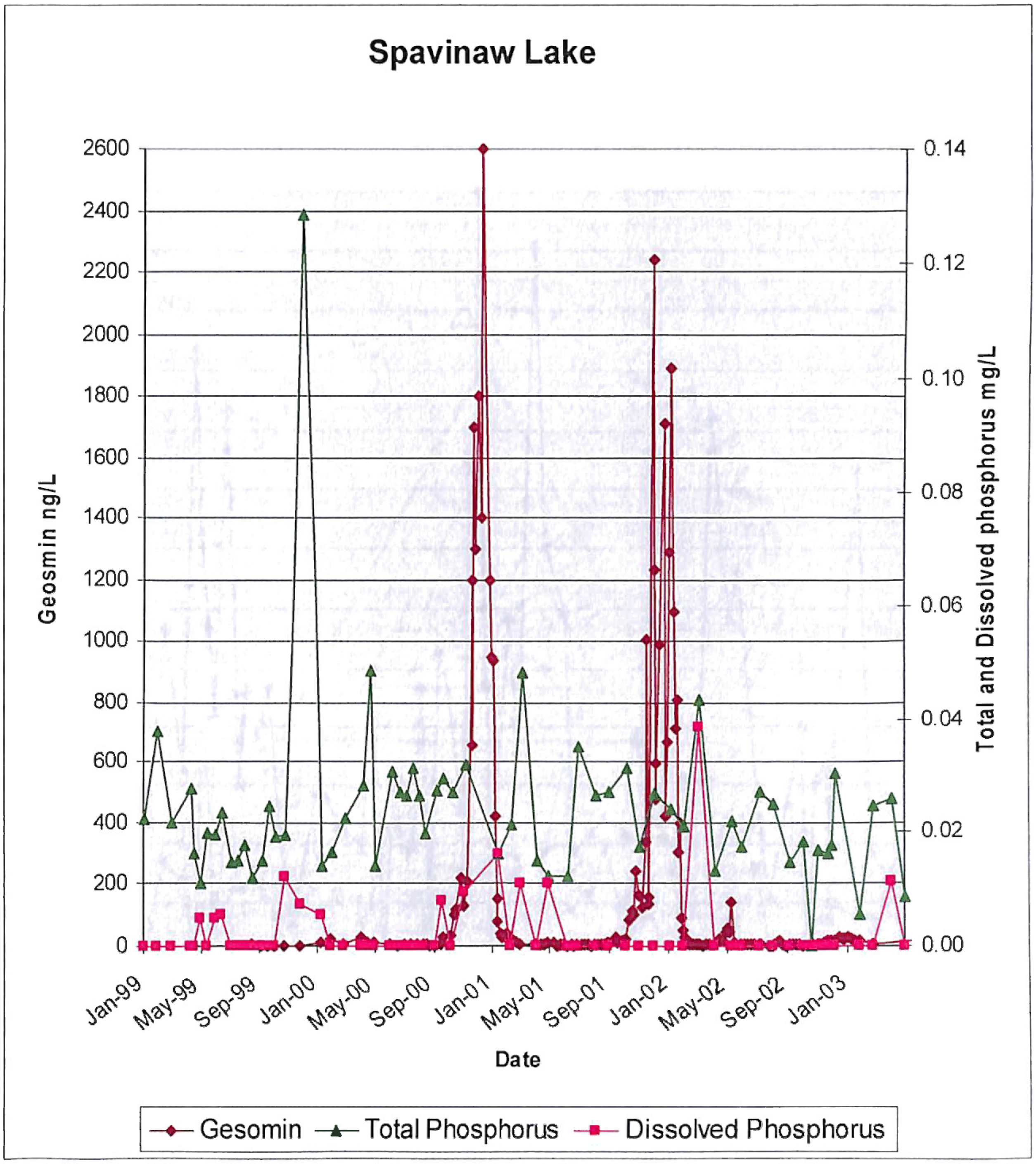

Figure 11. Geosmin in Lake Spavinaw, left scale, is compared to the total and dissolved phosphorus levels on the right scale. Highest geosmin occurs in autumn and winter. Total phosphorus fluctuates, but averages 0.024 mg/L for these years. (Source: City of Tulsa)

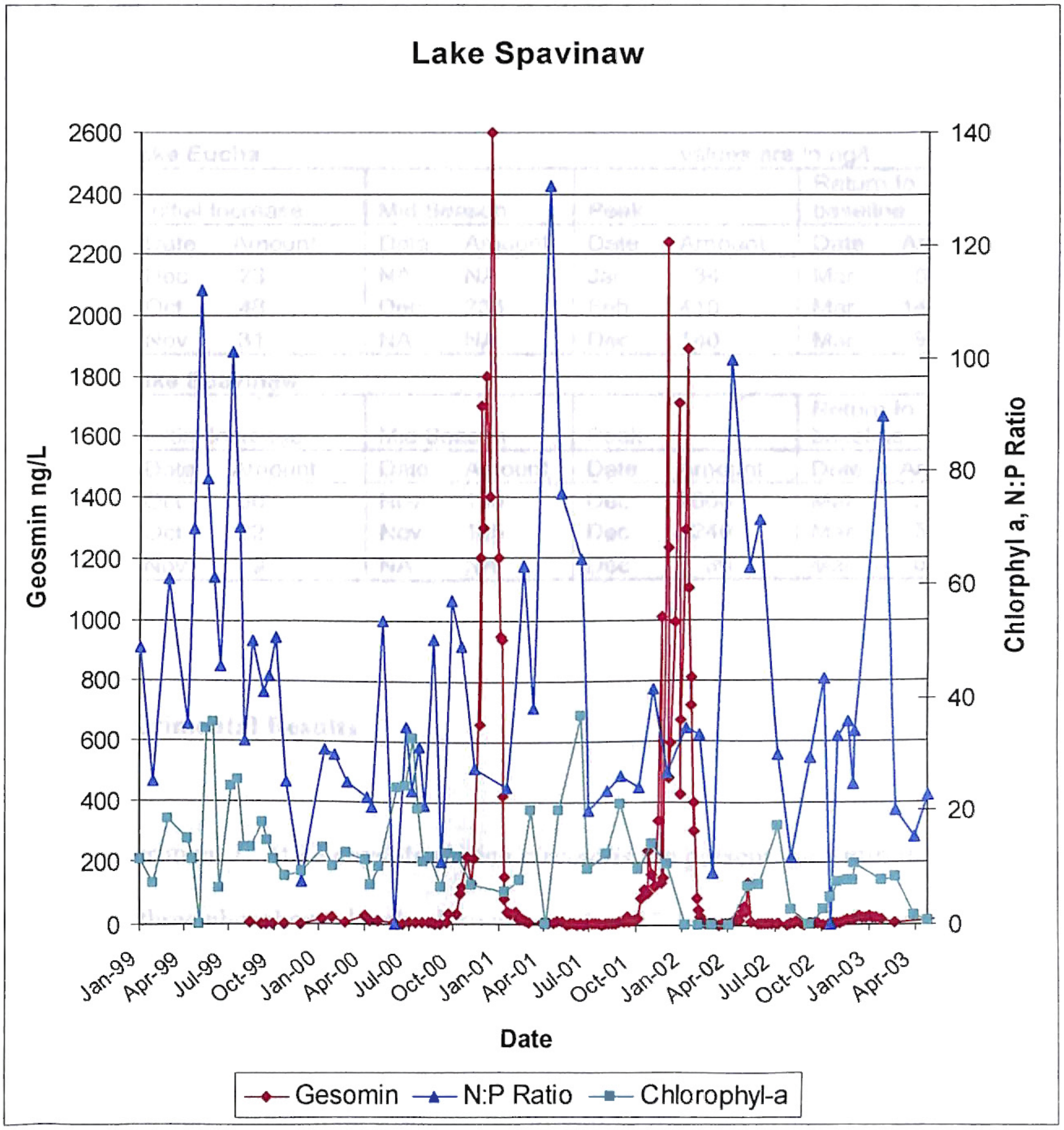

Figure 12. Lake Spavinaw geosmin values, left scale, compared to the N:P ratio and chlorophyll-*a,* right scale (Source: City of Tulsa).

Table 6. The progression of geosmin from the initial rise to a mid season value and the peak or highest value measured for the season. The last column gives the date geosmin values return to baseline (Source: City of Tulsa).

Geosmin Lake Eucha							values are in ng/L	
	Initial Increase		Mid Season		Peak		Return to baseline	
Year	Date	Amount	Date	Amount	Date	Amount	Date	Amount
2000-01	Dec	23	NA	NA	Jan	34	Mar	5
2001-02	Oct	48	Dec	233	Feb	410	Mar	14
2002-03	Nov	31	NA	NA	Dec	140	Mar	9
Geosmin Lake Spavinaw								
	Initial Increase		Mid Season		Peak		Return to baseline	
Year	Date	Amount	Date	Amount	Date	Amount	Date	Amount
2000-01	Oct	30	Nov	130	Dec	2600	Mar	3
2001-02	Oct	22	Nov	165	Dec	2240	Mar	5
2002-03	Nov	9	NA	NA	Dec	30	Mar	5

Experimental Results

Experiment 1: At 13 days *Anabaena circinalis* are present, geosmin is at baseline levels at all three phosphorus levels. Experiment 1 at 27 days, geosmin is again at baseline levels and no *Anabaena c.* were present at any of the phosphorus levels. At 39 days *Anabaena c.* were present in only one sample, the 200 μg/L-P sample. This sample produced 270 ng/L geosmin for a production of 0.0015 ng / cell (Table 7). Data for MIB (2-methylisoborneo), another known taste and odor compound, were provided with the geosmin analysis. This compound is produced by another genus of blue-green algae. The data are included here for future reference.

Table 7. Experiment 1 Results. Total plankton is measured in natural unit count, which is a colony count. Green, blue-green, diatoms and flagellate counts are a percentage of the total plankton count. Percent *A. circinalis* represents the percent of blue-green that are *Anabaena circinalis*. *A.circinalis* cells per liter are a cell count to provide a volume estimation. Geosmin and MIB (2-methylisoborneo) are nanograms per liter.

Date/Day	Geosmin	MIB	%Green	% Blue-Green	% Diatoms	% Flagellates	Total Plankton	% of BG= *A circinalis*	A circinalis cells/L
EXPERIMENT 1 20 µg/L P									
10/13/03 day 13	1.5	6.5	10	31	43	16	136000	23.8	70000
10/27/03 day 27	2.61	2.3	10	18	65	8	20000	0	0
11/9/03 day 39			11	13	65	11	226000	0	0
EXPERIMENT 1 200 µg/L P									
10/13/03 day 13	2	0.8	4	16	69	11	236000	10.5	104000
10/27/03 day 27	5.43	0.3	21	5	74	0	9500	0	0
11/9/03 day 39	270	1.9	12	16	68	5	154000	33.3	180000
EXPERIMENT 1 400 µg/L P									
10/13/03 day 13	5.5	4.6	12	18	50	21	136000	8.3	14000
10/27/03 day 27	3.62	1.3	17	5	64	14	29500	0	0
11/9/03 day 39			17	6	68	10	642000	0	0

These results are similar to experiments by Rashash et al.(1995) for *Anabaena laxa*, where low-P (360 µg/L) resulted in high geosmin production with a low population density. This is consistent with Saadoun et al. (2001) where geosmin production was seen when PO_4-P concentration was above 118 µg/L.

Experiment 2 (Table 8) had greater light, 10 hours of wide-spectrum bulb, natural sunlight and fluorescent light. The temperature was 15-30°C and greatly influenced by the current weather conditions. After 57 days algae blooms are visible and the bloom is *Anabaena circinalis.* Analysis confirms geosmin is present at low levels.

Table 8. Experiment 2 Results. A bloom of *Anabaena c.* is present on day 73 in 200 µg/L-P sample. Geosmin analysis on day 78 indicates geosmin is at low baseline levels. With higher light values more algae grows, but geosmin is at relatively low levels. Light is approximately $20 \mu E/m^2/s$ and temperature 20°C.

Date/Day	Geosmin	MIB	%Green	% Blue-Green	% Diatoms	% Flagellates	Total Plankton	% of BG= *A circinalis*	A circinalis cells/L
EXPERIMENT 2 20 µg/L P									
12/2/03 day 23	3.42	2	35	20	35	11	150000	0	0
12/14/03 day 37	16.9	2	12	11	68	9	812000	4.5	100000
1/5/04 day 57	4.06	2.7	4	11	85	1	628000	0	0
1/21/04 day 73			1	68	29	1	1.8E+07	0	0
1/26/04 day 78	6.96	1							
EXPERIMENT 2 200 µg/L P									
12/2/03 day 23	1.39	3.5	19	36	28	17	162000	0	0
12/14/03 day 37	29.1	2.8	33	14	12	42	172000	16.7	252000
1/5/04 day 57	1.6	3.2	14	6	69	11	420000	0	0
1/21/04 day 73	50.2	3.5							
1/26/04 day 78			4	93	1	2	1.8E+08	33.9	5.85E+08
12/2/03 day 23	5.74	4.2							
EXPERIMENT 2 400 µg/L P									
12/2/03 day 23	5.33	7.6	13	53	0	33	30000	0	0
12/14/03 day 37	70.3	4.3	20	15	50	15	160000	0	0
1/5/04 day 57	5.07	1.8	19	68	2	11	516000	0	0
1/21/04 day 73			1	66	31	3	7068000	3.3	3352000
1/26/04 day 78	3.18	0.4							
EXPERIMENT 2 Control									
12/14/03 day 37	5.3	4.3	69	12	17	1	2312000	0	0
1/5/04 day 57	0.58	2.6	40	3	57	0	1972000	0	0
1/21/04 day 73			28	4	67	0	6236000	0	0
1/26/04 day 78	0.65	2.1							

Experiment 3 consists of two identical sets of samples, again at phosphorus levels of 20, 200 and 400 μg/L. One set is again exposed to wide spectrum grow light for 10 hours per day, natural light and fluorescent light. The second set is exposed to wide-spectrum grow light only for 10 hours per day. Temperatures for both sets are the same.

Table 9. Experiment 3, Sunlight Plus Results. Bloom at day 26 declines at day 40. Light was approximately 200μE and temperature was 20°C.

Date	Geosmin	MIB	%Green	% Blue-Green	% Diatoms	% Flagellates	Total Plankton	% of BG= *A circinalis*	A circinalis cells/L
EXPERIMENT 3 20 μg/L P									
1/5/04 day 12	70.08	0	32	37	32	0	240,000	31.8	892,000
2/23/04 day 26	110	0	14	42	16	28	360000	97.4	2628000
3/8/04 day 40	73.7	0	18	3	71	8	1608000	92.9	840000
EXPERIMENT 3 200 μg/L P									
1/5/04 day 12	66.9	0	8	14	30	49	148,000	60	360,000
2/23/04 day 26	87.6	0	13	54	29	3	360000	93.9	4508000
3/8/04 day 40	31.49	0	33	10	34	22	420000	100	716000
EXPERIMENT 3 400 μg/L P									
1/5/04 day 12	67.1	0	20	24	27	29	180,000	63.6	900,000
2/23/04 day 26	74.5	0	12	41	19	28	232000	100	2456000
3/8/04 day 40	59.3	0	62	2	32	5	1996000	88.9	224000
EXPERIMENT 3 Control									
1/5/04 day 12	13.7	31	9	11	57	23	360,000	0	0
2/23/04 day 26	11.8	34	11	0	45	45	332000	0	0
3/8/04 day 40	48.35	19	32	0	56	12	236000	0	0

Table 10. Experiment 3, Limited light Results. Geosmin and cell counts decreased in all flasks. Light was approximately 14 $\mu E/m^2/s$ and temperature was 20°C.

Date	Geosmin	MIB	%Green	% Blue-Green	% Diatoms	% Flagellates	Total Plankton	% of BG= *A circinalis*	A circinalis cells/L
EXPERIMENT3 20 µg/L P									
2/15/04 day 19	43.7	0	2	15	50	37	240,000	85.7	432,000
3/1/04 day 33	25.4	31	30	12	42	15	132000	100	424000
3/15/04 day 47	17.4	8.8	10	8	59	22	196000	100	392000
EXPERIMENT 3 200 µg/L P									
2/15/04 day 19	35.8	16	27	21	27	24	132,000	100	704,000
3/1/04 day 33	27.7	47	39	13	9	39	92000	100	100000
3/15/04 day 47	27.4	16	14	8	47	31	196000	75	144000
EXPERIMENT 3 400 µg/L P									
2/15/04 day 19	33.1	22	21	7	54	18	224,000	50	184000
3/1/04 day 33	32.3	29	27	7	51	15	164000	100	140000
3/15/04 day 47	0	29	14	5	72	9	344000	25	100000
EXPERIMENT 3 Control									
2/15/04 day 19	31.7	67	0	59	38	3	128,000	100	3,028,000
3/1/04 day 33	34.9	184	7	17	63	13	184000	100	184000
3/15/04 day 47	22.8	118	26	10	56	8	248000	16.7	32000

Very few *Anabaena* colonies are required for geosmin to be present. As seen in Experiment 1, at 200 µg/L -P geosmin levels were 270 ng/L. Increased light and temperature do accelerate growth rates of the algae, but not the production of geosmin as illustrated in experiment 2. Much of the literature assumes a bloom of *Anabaena circinalis* will produce geosmin. Experiment 2 confirms that a bloom can be present with no geosmin produced.

The control sample was diluted but not fortified (spiked) with organic nitrogen or phosphorus. The results demonstrate that nutrients play an important role in species predominance. In the control sample green algae is predominant. In flasks altered with nitrogen and phosphorus blue-green algae and diatoms predominate. Diatoms typically predominate in cooler weather months. This shows the effect the nutrient levels can have on species populations.

Graphs 5-12 were generated to determine conditions for experiments based on four years of data from Lakes Eucha and Spavinaw. Examination of on-going circumstances shows the same pattern. *Anabaena circinalis* cells per liter measurements were also added to Figures 13 and 14, which document the most recent data (September 2003 – March 2004) from these lakes.

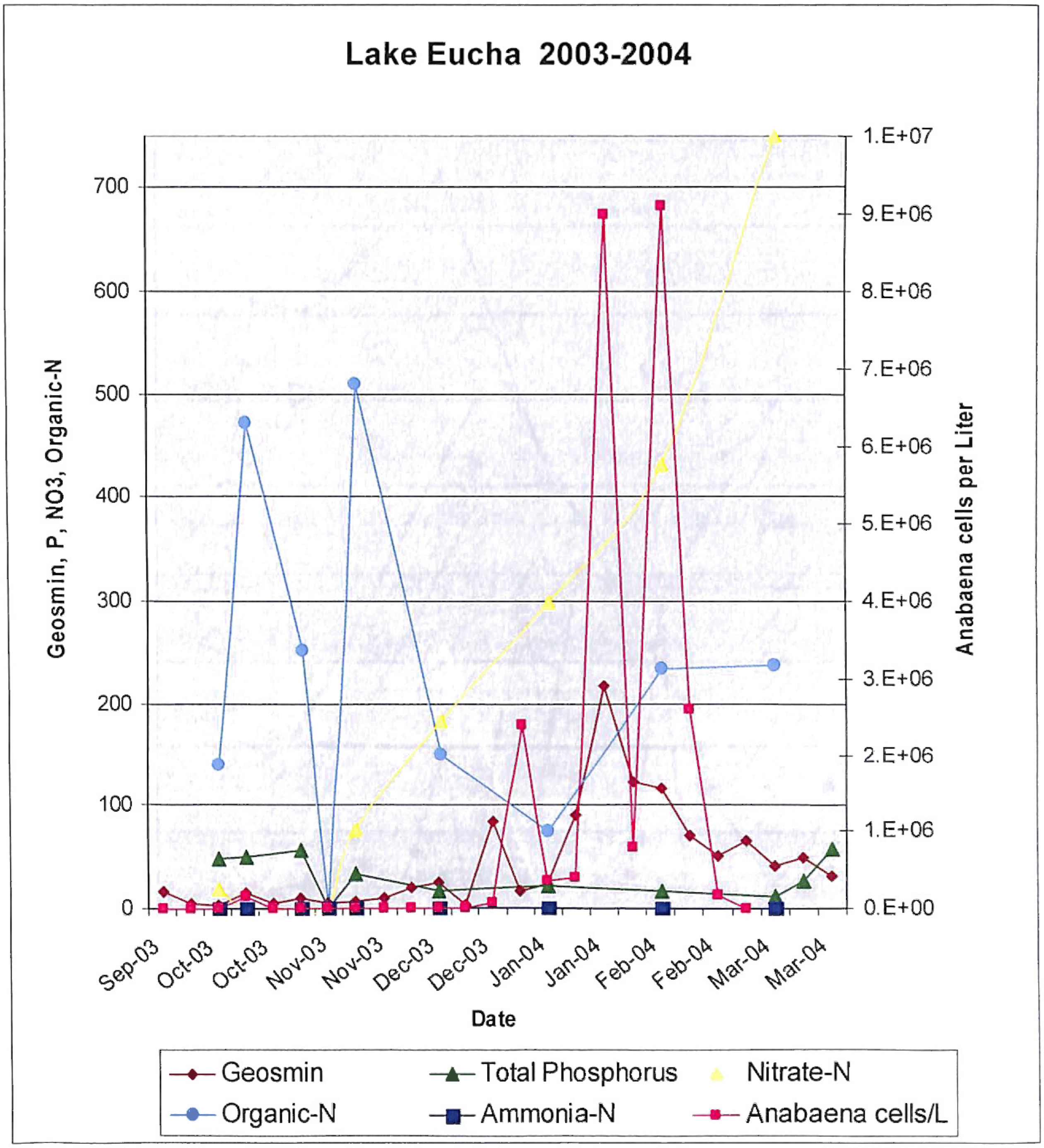

Figure 13 Graph of nutrients compared to geosmin and *Anabaena circinalis* cells/L in Lake Eucha. Note pattern of geosmin increase before there is an increase of *Anabaena c.* cells/L. The decrease in nitrate-N appears before the geosmin peak as in previous years (City of Tulsa data).

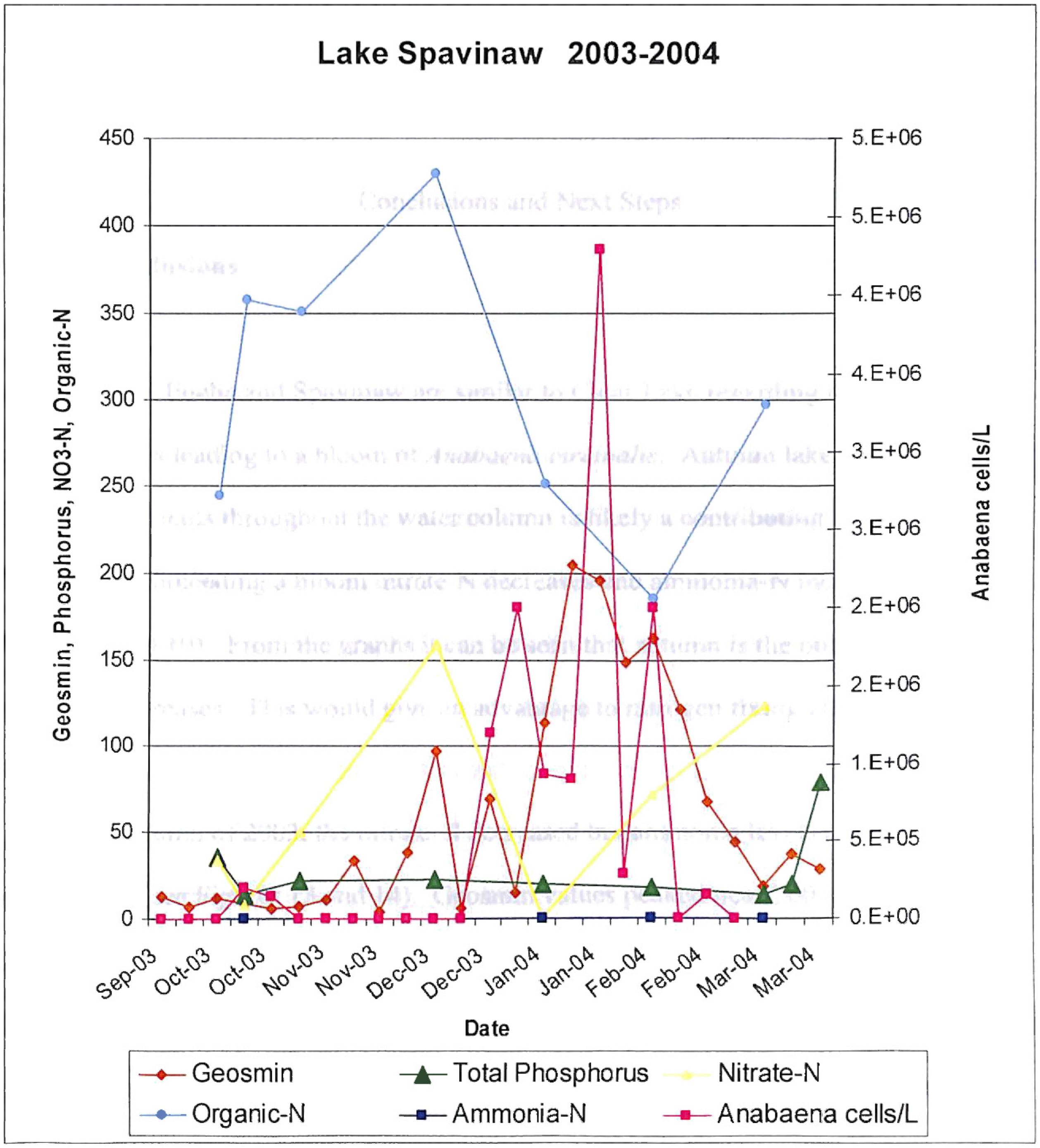

Figure 14 Graph of nutrients compared to geosmin and *Anabaena circinalis* cells/L in Lake Spavinaw. Note pattern of geosmin increase before there is an increase of *Anabaena c.* cells/L. The decrease in nitrate-N appears before the geosmin peak as in previous years (City of Tulsa data).

CHAPTER V

Conclusions and Next Steps

Conclusions

Lakes Eucha and Spavinaw are similar to Clear Lake regarding the set of circumstances leading to a bloom of *Anabaena circinalis*. Autumn lake turnover that suspends nutrients throughout the water column is likely a contributing factor. Historically, preceding a bloom nitrate-N decreases and ammonia-N increases (see Figures 6 and 10). From the graphs it can be seen that autumn is the only time the nitrate-N decreases. This would give an advantage to nitrogen fixing algae, such as *Anabaena*.

In autumn of 2003, the nitrate-N decreased but ammonia levels did not change appreciably (see Figures 13 and 14). Geosmin values peaked near 200 ng/L in the fall of 2003. Blue-green algae tend to proliferate in low N:P ratio situations. The chemical form of available nitrogen may be a significant factor to geosmin production.

Geosmin is produced in lower light conditions, but light conditions alone are not enough to trigger a bloom. For example, at lower light conditions and 20°C, experiment 3 did not produce high amounts of geosmin. In experiment 3, *Anabaena* colonies did increase but the geosmin production remained relatively constant (See Table 10).

The attempt to recreate the nutrients, light and temperature from Lakes Eucha and Spavinaw historical data produced the highest geosmin values in the laboratory setting.

The conditions for geosmin production in Lakes Eucha and Spavinaw were similar to those for Clear Lake (see Table 2). For Lakes Eucha and Spavinaw this would be ammonia in the range of 40-610 μg/L, nitrate 82-670 μg/L, organic nitrogen 190-900 μg/L, and phosphorus in the 17-60 μg/L range. These conditions combined with colder water temperature and shorter day light contributed to the highest geosmin production per *Anabaena* cell in experiment 1. It is possible that this trait may be an adaptation of the species found in Lakes Eucha and Spavinaw.

In experiment 1 the flask with 200 μg/L phosphorus produced the most geosmin of any of these experiments. The first microscopic examination confirmed that *Anabaena* was present. In the second examination no *Anabaena* were observed, yet *Anabaena* was present in the third examination. This leads to the speculation that geosmin could be associated with the germination of akinetes. In lake terms, it may be that the fall turnover suspends the akinetes and provides the needed nutrients for growth.

Experiment 2 (Table 8) shows that a bloom of *Anabaena circinalis* can be present with low geosmin production. Most literature regards a bloom as synonymous with geosmin production. Experiment 2 shows a definite bloom and geosmin levels near baseline levels. This would lead to the conclusion that circumstances for growth are not the same as those for geosmin production.

Further Research

Further study is needed to determine geosmin's contribution to cell metabolism. This compound could provide an additional energy source when light is insufficient for photosynthesis. In addition, geosmin can possibly supplement photosynthesis in times of rapid growth as in summer blooms. In prior studies, geosmin was found difficult to degrade microbiologically. The addition of ethanol accelerated the degradation process and proved to be an acceptable cometabolite (Saito et al., 1999). Geosmin may be a food source under anoxic conditions, such as those required by the nitrogenase activities of heterocysts. It may be that geosmin is produced when akinetes germinate. This may be the occurrence in experiment 1. Knowledge of the function of geosmin may be a key to the control of the production of this compound.

In terms of nutrients, phosphorus is present in low but sufficient levels year round for blue-green algae growth. Organic nitrogen was also at ample levels year-round. Autumn is the only time a reverse is seen where the nitrate-N decreases and ammonia-N increases (see Figures 6 and 10). The roles of the specific nitrogen forms should be looked at more closely. This difference was not specifically addressed in the experiments, but could be another contributing factor in geosmin production.

The species of *Anabaena circinalis* found in Lakes Eucha and Spavinaw may be an adapted species specific to this site. Colonies added to BG-11growth medium modified with reduced nitrate did not culture well. It would be expected that this species would flourish in this medium. Future research should isolate and culture *Anabaena c.* from these lakes. Further testing should be done to determine more exactly the algae's nutrient needs. Also this culture should be used in future experiments to add equivalence to experiments.

This study was limited in that only parameters from two sample sites were examined. Grab sample data taken from surface to 6 meters were averaged for a single value. Further study would involve more sample sites and treat each depth as a discrete sample. Samples taken to follow the movement of algae may provide information also.

Iron and manganese should be measured in the lakes. These elements are needed in the enzymatic nitrogen-fixing process. Knowledge of the levels of iron and manganese could be another key to predicting bloom conditions or geosmin producing conditions.

It is known that laboratory generated data may vary greatly from natural settings, in that not all conditions can be recreated. Investigation of nutrient concentration and ratios in continuous cultures or in-situ may yield more realistic results.

Steps are being taken to reduce the amount of phosphorus entering the Lakes Eucha and Spavinaw watershed. This is a good step to reduce the overall eutrophication occurring in the lakes. It remains to be seen if this step alone will alter the pattern of autumn and winter blooms and geosmin production of *Anabaena circinalis*.

REFERENCES

Agusti, S., Philips, E.J., 1992. Light Absorption by Cyanobacteria: Implication of colonial growth form. Limnology and Oceanography. 37:434-441.

Arthur, J.M., 2003. Personal correspondence, Ms. Arthur is plant superintendent of Mohawk Water Treatment Plant, Tulsa. jarthur@ci.tulsa.ok.us.

APHA, AWWA, and WEF. (1998) Standard Methods for the Examination of Water and Wastewater. 20th ed. APHA, Washington D.C.

Baker, L.A., 1994. Environmental chemistry of lakes and reservoirs. American Chemical Society, Washington D.C.

Barinaga, M., 1998. A new timepiece has a familiar ring. Science. 281:1429-1430.

Belcher, H., Swale, E. 1982. Culturing Algae, a guide for schools and colleges. Institute of Terrestrial Ecology. Cambridge, U.K.

Bowmer, K.H., Padovan, A., Oliver, R. L., Korth,W., Ganf, G.G., 1992. Physiology of Geosmin production by *Anabaena circinalis* isolated from the Murrumbidgee River, Australia. Water Science Technology 25: 259-267.

Bromley, S.M., 2000. Smell and taste disorders: A primary care approach. American Family Physician. 61: 2 427.

Bruchet, A., Anselme, C., Jammes, C., Mallevialle, J. 1995. Development of a taste and odor expert system: present state, strengths, limitations and possible future evolution. Water Science Technology 31: 243-250.

Busko, I., 2004. Comparison between light sources used in planted aquaria. www. aquabotanic.com/lightcompare.htm.

Carlson, S., 2000. How to rear a plankton menagerie. Scientific American. Aug:84-85

Codd, G.A., 2000. Cyanobacterial toxins, the perception of water quality and the prioritization of eutrophication control. Ecological Engineering 16: 51-60.

DeNobel, W.T., Matthijs, H.C.P., von Elert, E., Mur, L.R., 1998. Comparison of the light-limited growth of the nitrogen-fixing cyanobacteria *Anabaena* and *Aphanizomenon*. New Phytologist. 138:579-587.

Fay, P., 1988. Viability of akinetes of the planktonic cyanobacterium *Anabaena circinalis*. Proceeding of the Royal Society of London. 234: 283-301

Gagliardi, N., Stiff, C., 2003. Plant tissue culture archive, April 2003. http://plant-tc.coafes.umn.edu/listserv/2003/log0304/msg00149.html

Golden, J.W., Yoon, H.S., 1998. Heterocyst formation in *Anabaena*. Current Opinion in Microbiology. 1:623-629.

Gragnani, A., Scheffer, M., Rinaldi, S., 1999. Top-down control of cyanobacteria: A theoretical analysis. The American Naturalist. 153:59-72.

Graham, L.E., Wilcox, L. E., 2000. Algae. Prentice-Hall, Upper Saddle River, N.J.

Havens, K.E., James, R.T., East, T. L., Smith, V.H., 2003. N: P ratios, light limitation and cyanobacterial dominance in a subtropical lake impacted by non-point source nutrient pollution. Environmental Pollution 122:379-390.

Hitzfeld, B. Hoger, S.J., Dietrich, S.R., 2000.Cyanobacterial toxins: removal during drinking water treatment and human risk assessment. Environmental Health Perspectives 108 (suppl 1) 113-122.

Hoff, F.H., Snell, T.W. 1987. Plankton Culture Manual. Florida Aqua Farms, Dade City, Florida.

Hori, K., Okamoto, J., Tanji, Y., Unno, H., 2002. Formation, sedimentation and germination properties of *Anabaena* akinetes. Biochemical Engineering Journal 3662:1-7.

Horne, A.J., Goldman, C.R., 1972. Nitrogen fixation in Clear Lake, California. I. Seasonal variation and the role of heterocysts. Limnology and Oceanography 17: 678-692.

Horne, A.J., Dillard, J.E., Fujita, D.K., Goldman, C.R., 1972. Nitrogen fixation in Clear Lake, California. II. Synoptic studies on the autumn *Anabaena* bloom. Limnology and Oceanography 17: 693-703.

http://www.deq.state.ok.us/rules/631.pdf. 2003. 252:631-3-10. Process control tests (4)C. 5.

http://www.tulsawater.com. Tulsa Metropolitan Utility Authority.

Johnson, C.H., Golden, S.S., 1999. Circadian programs in cyanobacteria : adaptiveness and mechanism. Annual Review of Microbiology. 53:389-409.

Lam, S., 2003. Day length for various latitudes. www.orchidculture.com/COD/daylength.html.

Lassek, P.J. 12/5/1999. City works to treat water woes. The Tulsa World, World Publishing Co, Tulsa, OK.

Lassek, P.J. 3/12/00. Water-System job targets odor, taste. The Tulsa World, World Publishing Co, Tulsa, OK.

Lassek, P.J. 7/23/2003. Councilor defends poultry lawsuit settlement. The Tulsa World, World Publishing Co, Tulsa, OK.

Li, R., Watanabe, M., Watanabe, M., 1997. Akinete formation in plantonic *Anabaena* spp. (Cyanobacteria) by treatment with low temperature. Journal of Phycology. 33:576-584.

Lu, G., Edwards, C.G., Fellman, J.K., Mattinson, D. S., Navazio, J., 2003. Biosynthetic origin of geosmin in red beets (*Beta vulgaris* L.) Journal of Agricultural Food Chemistry 10:1021

Maier, H.R., Dandy, F.C., Burch, M.D., 1998. Use of artificial neural networks for modeling cyanobacterial *Anabaena* spp. in the River Murray, South Australia. Ecological Modelling 105:257-272.

Naes, H., Aarnes, H., Utkilen, H.C., Nilsen, S., Skulberg, O.M., 1985. Effect of photon fluence rate and specific growth rate on geosmin production of the cyanobacterium *Oscillatoria brevis* (Kutz.) Gom. Applied and Environmental Microbiology. 49,6: 1538-1540.

Newcombe, G., Burch, M., 2003. Toxic blue-green algae: Coming to a neighborhood near you? Opflow 29:1-7

Oklahoma Water Resources Board. April 11,2001. Nutrient Goal setting for the Eucha-Spavinaw-Yahola Lake Complex.

Paerl, H.W., 1978. Factors regulating nuisance blue-green algal bloom potentials in the lower Neuse River, NC. WRI of the University of NC. Project No A-122-NC.

Rashash, D.M.C., Dietrich, A.M., Hoehn, R.C., Parker, B.C., 1995. The influence of growth conditions on odor-compound production by two chrysophytes and two cyanobacteria. Water Science Technology. 31:165-172.

Reynolds, C.S., Reynolds, S.N., Munawar, I.F., Munawar, M., 2000.The regulation of phytoplankton population dynamics in the world's largest lakes. Aquatic Ecosystem Health and Mgt. 3:1-21.

Rhee, G.Y., Gotham, I.J., 1981. The effects of environmental factors on phytoplankton growth: temperature and interactions of temperature with nutrient limitation. Limnology and Oceanography. 26:635-648.

Round, F.E., 1961. Studies on bottom-living algae in some lakes of the English Lake District Part V. The seasonal cycles of the cyanophyceae. Journal of Ecology. 49:31-38.

Saadoun, I.M.K., Schrader, K.K., Blevins, W. T., 2001. Environmental and nutritional factors affecting geosmin synthesis by *Anabaena* sp. Water Resources 35:1209-1218.

Saito, A., Tokuyama, T., Tanaka A., Oritani, T., Fuchigami, K.,1999. Microbiological degradation of (-)-Geosmin. Water Resources 33:3033-3036.

Sinha, R.P., Hader, D.P., 1996. Response of a rice field cyanobacterium *Anabaena sp.* to physiological stressors. Environmental and Experimental Botany. 36:147-155.

Storm, D.E., White, M., Smolen, M.D., Zhang, H., 2001. Modeling phosphorous loading for the Lake Eucha Basin. Report to Tulsa Metropolitan Utility Authority. (Nov-1-2001) http://biosystems.okstate.edu/Home/dstorm/index.html.

Ternus, M. 1995. Water, water everywhere – but is it safe to drink? Environmental Nutrition. 18:9-12.

USEPA (US Environmental Protection Agency),2003. National Secondary Drinking Water Regulations. 40CFR part 143.

Volk, T., 1998. Gaia's Body, toward a physiology of Earth. Springer-Verlag, New York.

Von Elert, E., Juttner, F., 1997.Phosphorus limitation and not light controls the extracellular release of alleopathic compounds by *Trichormus doliolum* (cyanobacteria). Limnology and Oceanography. 42:1796-1802.

Watson, S.B., Brownlee, B., Satchwill, T., Hargesheimer, E.E., 2000. Quantitative analysis of trace levels of geosmin and MIB in source and drinking water using headspace SPME. Water Resources 34:2118-2828

Wehr, J.D., Sheath, R.G., 2003. Freshwater Algae of North America, Ecology and Classification. Academic Press, New York.

Wetzel, R.G., Likens, G.E., 2000. Limnological Analyses. Springer-Verlag, New York.

Winder, J.A., Cheng, M. H., 1995. Quantification of factors controlling the development of *Anabaena* circinalis Blooms. Urban Water Research Association of Australia. Report No. 88.

Yoo, R.S., Carmichael, W.W., Hoehn, R.C., Hrudey, S.E., 1995. *Cyanobacterial (Blue-Green Algal) Toxins: A Resource Guide.* AWWA Research Foundation and American Water Works Association, Denver Co.

APPENDIX

(City of Tulsa data)

Lake	STATION	AIRTEMP	TEMPC	SAT	D.O.	pH	COND
Spavinaw				D.O.			
				%			
01/14/99	SPA01		3.3	95.6	12.8	8.46	211
02/10/99	SPA01		9.8	94.2	10.7	7.93	228
03/11/99	SPA01		9.7	98.6	11.2	8.54	230
04/20/99	SPA01		15.1	103.2	10.4	8.35	221
04/29/99	SPA01		17.0	0.0	8.9	8.13	230
05/12/99	SPA01		19.2	85.8	7.9	8.07	217
05/26/99	SPA01		21.0	85.2	7.5	8.00	199
06/10/99	SPA01		24.9	87.0	6.9	8.35	189
06/24/99	SPA01		23.2	72.2	6.1	7.89	194
07/15/99	SPA01		26.4	123.0	9.8	8.27	180
07/29/99	SPA01		28.3	101.5	7.5	8.20	169
08/11/99	SPA01		29.6	74.0	5.5	8.23	174
08/26/99	SPA01		28.3	84.7	6.6	8.29	176
09/16/99	SPA01		24.7	84.2	7.0	7.99	179
09/29/99	SPA01		21.1	70.1	6.2	7.62	165
10/12/99	SPA01		21.1	116.5	10.3	8.51	181
11/04/99	SPA01		15.4	72.6	7.3	7.75	198
12/07/99	SPA01		11.4	76.8	8.4	7.68	213
01/19/00	SPA01	8.8	7.6	89.7	10.7	8.42	223
02/09/00	SPA01	10.50	5.0	89.3	11.4	8.26	221
03/07/00	SPA01	16.5	11.7	58.4	6.3	8.36	213
04/13/00	SPA01	10.8	14.6	88.8	9.0	8.03	257
04/26/00	SPA01	16	17.2	87.1	8.4	8.13	240
05/11/00	SPA01	23.7	20.2	71.7	6.5	7.66	254
06/13/00	SPA01	25.3	24.9	67.6	5.6	8.15	212
06/29/00	SPA01	21.5	24.7	62.0	5.1	8.03	203
07/13/00	SPA01	29.7	29.0	81.5	6.1	8.38	154
07/27/00	SPA01	30.2	27.7	81.2	6.3	8.55	170
08/10/00	SPA01	28.4	29.3	84.1	6.4	8.50	156
08/24/00	SPA01	28.3	29.1	86.1	6.6	8.52	165
08/28/00	SPA01						
09/05/00	SPA01						
09/14/00	SPA01	25.7	27.6	66.0	5.2	7.86	176
09/28/00	SPA01	15.4	21.3	51.4	3.9	7.52	195
10/02/00	SPA01						
10/17/00	SPA01	15.6	18.1	79.3	7.5	7.70	182
10/24/00	SPA01						
10/30/00	SPA01						
11/07/00	SPA01						
11/16/00	SPA01	5.80	11.6	65.7	7.1	7.83	193
11/20/00	SPA01						
11/28/00	SPA01						
11/29/00	SPA01						
11/30/00	SPA01						

Lake	STATION	AIRTEMP	TEMP©	SAT	D.O.	pH	COND
Spavinaw				D.O.			
				%			
12/05/00	SPA01						
12/11/00	SPA01						
12/18/00	SPA01						
12/20/00							
01/03/01	SPA01						
01/08/01	SPA01						
01/10/01	SPA01						
01/17/01	SPA01						
01/23/01	SPA01	2.80	2.8	90.3	12.2	7.78	197
01/24/01	SPA01						
01/29/04	SPA01						
01/31/01	SPA01						
02/05/01	SPA01						
02/07/01	SPA01						
02/14/01	SPA01						
02/22/01	SPA01	-3.3	5.9	90.7	11.3	8.25	219
02/28/01	SPA01						
03/07/01	SPA01						
03/13/01	SPA01	7.8	8.6	97.5	11.4	7.88	212
04/11/01	SPA01						
04/16/01	SPA01	7.8	18.0	96.3	9.1	8.47	208
04/25/01	SPA01						
05/02/01	SPA01						
05/09/01	SPA01	14.4	22.3	106.1	9.2	8.48	194
05/21/01	SPA01						
05/30/01	SPA01						
06/06/01	SPA01						
06/13/01	SPA01						
06/20/01	SPA01	24.6	27.1	116.2	9.2	8.56	142
06/27/01	SPA01						
07/02/01	SPA01						
07/10/01	SPA01	26.5	29.1	84.8	6.4	8.64	142
07/18/01	SPA01						
07/25/01	SPA01						
08/01/01	SPA01						
08/08/01	SPA01						
08/14/01	SPA01	22.1	30.4	70.5	5.3	8.52	162
08/22/01	SPA01						
08/29/01	SPA01						
09/05/01	SPA01						
09/11/01	SPA01	17	26.2	62.8	5.1	7.67	171
09/19/01	SPA01						
09/26/01	SPA01						
10/02/01	SPA01						

Lake	STATION	AIRTEMP	TEMP©	SAT	D.O.	pH	COND
Spavinaw				D.O.			
				%			
10/10/01	SPA01						
10/17/01	SPA01	12.2	17.8	62.1	5.9	7.59	186
10/23/01	SPA01						
10/31/01	SPA01						
11/05/01	SPA01						
11/07/01	SPA01						
11/14/01	SPA01	17.2	15.7	72.4	7.2	7.64	209
11/19/01	SPA01						
11/26/01	SPA01						
11/28/01	SPA01						
12/03/01	SPA01						
12/05/01	SPA01						
12/10/01	SPA01						
12/13/01	SPA01	8.9	10.2	79.7	8.9	8.14	200
12/16/01	SPA01						
12/19/01	SPA01						
12/26/01	SPA01						
01/02/02	SPA01						
01/07/02	SPA01						
01/09/02	SPA01						
01/14/02	SPA01						
01/17/02	SPA01	1.1	4.5	84.0	10.9	8.05	238
01/23/02	SPA01						
01/28/02	SPA01						
01/30/02	SPA01						
02/04/02	SPA01						
02/06/02	SPA01						
02/11/02	SPA01						
02/14/02	SPA01	0.8	5.7	86.3	10.8	8.01	247
02/18/02	SPA01						
02/20/02	SPA01						
02/25/02	SPA01						
02/27/02	SPA01						
03/05/02	SPA01						
03/11/02	SPA01						
03/14/02	SPA01	0	7.9	93.1	11.0	7.91	252
03/18/02	SPA01						
03/25/02	SPA01						
04/01/02	SPA01						
04/08/02	SPA01						
04/17/02	SPA01	21	16.7	90.3	8.8	8.01	260
04/22/02	SPA01						
04/29/02	SPA01						
05/06/02	SPA01						

Lake	STATION	AIRTEMP	TEMP©	SAT	D.O.	pH	COND
Spavinaw				D.O.			
				%			
05/13/02	SPA01						
05/16/02	SPA01						
05/20/02	SPA01						
05/22/02	SPA01	18.00	20.3	102.0	9.2	8.37	242
05/28/02	SPA01						
06/11/02	SPA01	0	25.1	90.4	7.3	8.14	211
06/17/02	SPA01						
06/24/02	SPA01						
07/01/02	SPA01						
07/08/02	SPA01						
07/17/02	SPA01	23	28.1	8.9	114.3	8.43	176
07/22/02	SPA01						
07/29/04	SPA01						
08/06/02	SPA01						
08/12/02	SPA01						
08/15/02	SPA01	25.5	27.6	130.5	10.3	8.11	189
08/19/02	SPA01						
08/26/02	SPA01						
09/03/02	SPA01						
09/09/02	SPA01						
09/18/02	SPA01	24.5	25.8	65.8	5.4	7.71	198
09/23/02	SPA01						
09/30/02	SPA01						
10/07/02	SPA01						
10/15/02	SPA01	6	19.2	61.4	5.7	38.89	206
10/30/02	SPA01	0.37	15.4	0.0	0.0	7.66	205
11/04/02	SPA01						
11/13/02	SPA01	9.50	12.5	92.9	9.9	7.76	206
11/18/02	SPA01						
11/25/02	SPA01						
12/02/02	SPA01	12.50	8.8	87.6	10.2	7.86	215
12/11/02	SPA01	5.5	6.8	88.7	10.8	8.00	217
12/16/02	SPA01	7	6.2	97.4	12.0	8.04	226
12/26/02	SPA01						
01/02/03	SPA01						
01/06/03	SPA01						
01/13/03	SPA01						
01/21/03	SPA01						
01/27/03	SPA01						
02/05/03	SPA01	1	5.5	104.2	13.1	8.05	231
03/06/03	SPA01	-2	4.9	96.9	12.4	8.08	238
04/10/03	SPA01	4	13.6	84.8	8.8	7.70	241
05/07/03	SPA01	17	22.0	107.0	9.4	8.35	239

Lake	ALK	T-PO4	D-PO4	T.HARD	NH3	NO3	NO2
Spavinaw							
01/14/99	94.0	0.022	0	102.3	0.00	0.602	0.000
02/10/99	96.8	0.038	0	105.3	0.00	0.948	0.000
03/11/99	96.8	0.022	0	105.0	0.00	0.900	0.000
04/20/99	93.3	0.028	0	101.5	0.00	0.924	0.049
04/29/99	90.0	0.016	0	99.0	0.07	1.043	0.000
05/12/99	91.5	0.011	0.005	98.3	0.53	1.225	0.033
05/26/99	82.8	0.020	0	89.5	0.10	0.864	0.000
06/10/99	66.3	0.020	0.005	71.0	0.00	0.470	0.000
06/24/99	80.0	0.023	0.0055	83.8	0.07	0.357	0.035
07/15/99	70.8	0.015	0	72.8	0.10	0.450	0.034
07/29/99	64.5	0.015	0	64.5	0.36	0.000	0.000
08/11/99	66.0	0.018	0	67.3	0.22	0.000	0.000
08/26/99	73.0	0.012	0	72.3	0.00	0.000	0.000
09/16/99	76.8	0.015	0	75.3	0.07	0.000	0.000
09/29/99	81.0	0.025	0	80.0	0.43	0.065	0.000
10/12/99	85.0	0.019	0	84.0	0.26	0.112	0.000
11/04/99	89.5	0.020	0.0123	89.5	0.23	0.146	0.000
12/07/99	93.8	0.129	0.0073	97.5	0.14	0.281	0.000
01/19/00	99.8	0.014	0.006	104.8	0.00	0.207	0.000
02/09/00	102.8	0.017	0.000	107.0	0.00	0.163	0.000
03/07/00	102.0	0.023	0	107.8	0.00	0.090	0.000
04/13/00	108.0	0.028	0	111.0	0.00	0.173	0.000
04/26/00	106.3	0.049	0	111.3	0.00	0.176	0.000
05/11/00	106.0	0.014	0	106.3	0.00	0.250	0.000
06/13/00	87.0	0.031	0	87.3	0.00	0.000	0.000
06/29/00	78.5	0.027	0	78.8	0.00	0.110	0.000
07/13/00	66.0	0.026	0	52.3	0.10	0.051	0.000
07/27/00	68.0	0.031	0	65.0	0.13	0.000	0.000
08/10/00	65.5	0.026	0	62.5	0.12	0.038	0.000
08/24/00	64.8	0.020	0	64.8	0.04	0.000	0.000
08/28/00							
09/05/00							
09/14/00	72.5	0.027	0	70.0	0.13	0.172	0.000
09/28/00	80.8	0.030	0.008	76.5	0.33	0.068	0.000
10/02/00							
10/17/00	82.5	0.027	0	81.3	0.11	0.116	0.000
10/24/00							
10/30/00							
11/07/00							
11/16/00	86.5	0.032	0.010	91.0	0.16	0.178	0.016
11/20/00							
11/28/00							
11/29/00							
11/30/00							

Lake	ALK	T-PO4	D-PO4	T.HARD	NH3	NO3	NO2
Spavinaw							
12/05/00							
12/11/00							
12/18/00							
12/20/00							
01/03/01							
01/08/01							
01/10/01							
01/17/01							
01/23/01	95.5	0.016	0.016	97.0	0.06	0.298	0.000
01/24/01							
01/29/04							
01/31/01							
02/05/01							
02/07/01							
02/14/01							
02/22/01	102.5	0.021	0	104.3	0.06	0.858	0.000
02/28/01							
03/07/01							
03/13/01	86.0	0.049	0.011	96.3	0.00	1.928	0.000
04/11/01							
04/16/01	80.0	0.015	0	86.0	0.07	1.600	0.000
04/25/01							
05/02/01							
05/09/01	80.0	0.012	0.011	85.0	0.00	1.290	0.024
05/21/01							
05/30/01							
06/06/01							
06/13/01							
06/20/01	51.3	0.012	0	52.0	0.00	0.200	0.040
06/27/01							
07/02/01							
07/10/01	53.3	0.035	0	53.0	0.11	0.030	0.000
07/18/01							
07/25/01							
08/01/01							
08/08/01							
08/14/01	58.5	0.026	0	58.5	0.07	0.000	0.000
08/22/01							
08/29/01							
09/05/01							
09/11/01	67.5	0.027	0	67.3	0.12	0.029	0.000
09/19/01							
09/26/01							
10/02/01							

Lake	ALK	T-PO4	D-PO4	T.HARD	NH3	NO3	NO2
Spavinaw							
10/10/01							
10/17/01	77.5	0.031	0	77.5	0.22	0.110	0.020
10/23/01							
10/31/01							
11/05/01							
11/07/01							
11/14/01	87.5	0.017	0	90.0	0.08	0.113	0.000
11/19/01							
11/26/01							
11/28/01							
12/03/01							
12/05/01							
12/10/01							
12/13/01	92.3	0.027	0	95.8	0.12	0.185	0.000
12/16/01							
12/19/01							
12/26/01							
01/02/02							
01/07/02							
01/09/02							
01/14/02							
01/17/02	100.0	0.024	0	105.5	0.00	0.350	0.022
01/23/02							
01/28/02							
01/30/02							
02/04/02							
02/06/02							
02/11/02							
02/14/02	105.0	0.021	0	106.0	0.04	0.336	0.000
02/18/02							
02/20/02							
02/25/02							
02/27/02							
03/05/02							
03/11/02							
03/14/02	103.3	0.044	0.0388	107.8	0.05	0.440	0.000
03/18/02							
03/25/02							
04/01/02							
04/08/02							
04/17/02	104.7	0.013	0	110.5	0.05	0.798	0.000
04/22/02							
04/29/02							

Lake	ALK	T-PO4	D-PO4	T.HARD	NH3	NO3	NO2
Spavinaw							
05/13/02							
05/16/02							
05/20/02							
05/22/02	103.0	0.022	0.000	108.8	0.11	0.638	0.000
05/28/02							
06/11/02	85.3	0.017	0	86.8	0.10	0.493	0.020
06/17/02							
06/24/02							
07/01/02							
07/08/02							
07/17/02	64.3	0.027	0	65.3	0.11	0.000	0.000
07/22/02							
07/29/04							
08/06/02							
08/12/02							
08/15/02	76.0	0.025	0	75.0	0.04	0.036	0.000
08/19/02							
08/26/02							
09/03/02							
09/09/02							
09/18/02	79.5	0.015	0	78.3	0.08	0.000	0.000
09/23/02							
09/30/02							
10/07/02							
10/15/02	85.5	0.018	0	85.5	0.19	0.000	0.000
10/30/02	85.0	0.000	0.000	88.8	0.00	0.000	0.000
11/04/02							
11/13/02	89.0	0.017	0.000	89.0	0.04	0.082	0.000
11/18/02							
11/25/02							
12/02/02	94.8	0.016	0.000	92.0	0.15	0.095	0.000
12/11/02	92.8	0.018	0	93.0	0.04	0.088	0.000
12/16/02	96.5	0.030	0	96.5	0.56	0.080	0.000
12/26/02							
01/02/03							
01/06/03							
01/13/03							
01/21/03							
01/27/03							
02/05/03	100.0	0.006	0	100.0	0.06	0.077	0.000
03/06/03	103.3	0.025	0	103.5	0.06	0.076	0.000
04/10/03	105.0	0.026	0.0113	110.5	0.13	0.053	0.000
05/07/03	106.0	0.009	0	106.0	0.05	0.059	0.081

Lake	NO2+NO3	TKN	Organic N	TDS	TSS	SET.SOL	SI
Spavinaw			TKN-NH3				
01/14/99	0.612	0.49	0.49	147.25	8.00	0.00	0.00
02/10/99	0.971	0.00	0.00	128.00	4.00	0.00	0.66
03/11/99	0.924	0.41	0.41	151.00	5.12	0.00	0.00
04/20/99	0.973	0.00	0.00	130.25	0.00	0.00	0.00
04/29/99	1.065	0.00	0.00	92.15	0.00	0.00	0.00
05/12/99	1.255	0.00	0.00	140.00	0.00	0.00	1.04
05/26/99	0.881	0.59	0.50	120.75	0.00	0.00	1.38
06/10/99	0.492	1.03	1.03	80.63	0.00	0.00	2.15
06/24/99	0.379	0.86	0.80	116.75	0.00	0.00	3.05
07/15/99	0.482	0.88	0.78	128.50	0.00	0.00	3.78
07/29/99	0.000	0.69	0.33	185.50	0.00	0.00	4.08
08/11/99	0.000	0.35	0.13	127.75	0.00	0.00	3.90
08/26/99	0.000	0.59	0.59	96.25	0.00	0.00	4.18
09/16/99	0.000	0.55	0.48	135.00	0.00	0.00	4.88
09/29/99	0.068	0.59	0.17	131.67	0.00	0.00	5.27
10/12/99	0.117	0.60	0.34	120.67	0.00	0.00	5.10
11/04/99	0.146	0.41	0.18	89.40	0.00	0.00	0.93
12/07/99	0.291	0.57	0.43	96.75	0.00	0.00	3.18
01/19/00	0.210	0.39	0.39	120.70	0.00	0.00	1.02
02/09/00	0.163	0.33	0.33	142.25	0.00	0.00	0.78
03/07/00	0.090	0.47	0.47	144.50	0.00	0.00	0.00
04/13/00	0.175	0.46	0.46	150.75	0.00	0.00	0.00
04/26/00	0.176	0.83	0.83	106.45	0.00	0.00	0.00
05/11/00	0.250	0.50	0.50	134.50	0.00	0.00	0.95
06/13/00	0.000	0.00	0.00	114.20	0.00	0.00	1.98
06/29/00	0.127	0.83	0.83	85.05	0.00	0.00	2.50
07/13/00	0.051	0.46	0.36	93.70	0.00	0.00	2.73
07/27/00	0.000	0.85	0.72	102.65	0.00	0.00	3.40
08/10/00	0.042	0.39	0.27	113.75	0.00	0.00	3.65
08/24/00	0.021	0.96	0.91	68.00	0.00	0.00	4.00
08/28/00							
09/05/00							
09/14/00	0.174	0.00	0.00	61.90	0.00	0.00	4.83
09/28/00	0.068	1.75	1.42	134.75	0.00	0.00	5.20
10/02/00							
10/17/00	0.115	1.11	1.01	117.25	0.00	0.00	4.30
10/24/00							
10/30/00							
11/07/00							
11/16/00	0.195	0.78	0.62	149.50	0.00	0.00	3.85
11/20/00							
11/28/00							
11/29/00							
11/30/00							

Lake	NO2+NO3	TKN	Organic N	TDS	TSS	SET.SOL	SI
Spavinaw			TKN-NH3				
12/05/00							
12/11/00							
12/18/00							
12/20/00							
01/03/01							
01/08/01							
01/10/01							
01/17/01							
01/23/01	0.298	0.41	0.35	146.00	0.00	0.00	2.75
01/24/01							
01/29/04							
01/31/01							
02/05/01							
02/07/01							
02/14/01							
02/22/01	0.858	0.42	0.35	141.25	0.00	0.00	1.68
02/28/01							
03/07/01							
03/13/01	1.900	0.36	0.36	114.25	0.00	0.00	2.33
04/11/01							
04/16/01	1.600	0.29	0.21	119.75	0.00	0.00	0.00
04/25/01							
05/02/01							
05/09/01	1.300	0.44	0.44	89.83	0.00	0.00	0.66
05/21/01							
05/30/01							
06/06/01							
06/13/01							
06/20/01	0.210	0.53	0.53	90.50	0.00	0.00	1.42
06/27/01							
07/02/01							
07/10/01	0.031	0.56	0.44	81.70	0.00	0.00	1.61
07/18/01							
07/25/01							
08/01/01							
08/08/01							
08/14/01	0.000	0.54	0.47	97.78	0.00	0.00	2.08
08/22/01							
08/29/01							
09/05/01							
09/11/01	0.033	0.56	0.45	135.50	0.00	0.00	2.61
09/19/01							
09/26/01							
10/02/01							

Lake	NO2+NO3	TKN	Organic N	TDS	TSS	SET.SOL	SI
Spavinaw			TKN-NH3				
10/10/01							
10/17/01	0.123	0.41	0.19	106.50	0.00	0.00	2.76
10/23/01							
10/31/01							
11/05/01							
11/07/01							
11/14/01	0.128	0.53	0.45	96.83	0.00	0.00	1.26
11/19/01							
11/26/01							
11/28/01							
12/03/01							
12/05/01							
12/10/01							
12/13/01	0.195	0.42	0.30	117.75	0.00	0.00	1.86
12/16/01							
12/19/01							
12/26/01							
01/02/02							
01/07/02							
01/09/02							
01/14/02							
01/17/02	0.363	0.46	0.46	0.00	0.00	0.00	2.60
01/23/02							
01/28/02							
01/30/02							
02/04/02							
02/06/02							
02/11/02							
02/14/02	0.330	0.33	0.29	0.00	0.00	0.00	1.40
02/18/02							
02/20/02							
02/25/02							
02/27/02							
03/05/02							
03/11/02							
03/14/02	0.448	0.27	0.22	0.00	0.00	0.00	0.52
03/18/02							
03/25/02							
04/01/02							
04/08/02							
04/17/02	0.798	0.45	0.41	0.00	0.00	0.00	0.58
04/22/02							
04/29/02							
05/06/02							

Lake	NO2+NO3	TKN	Organic N	TDS	TSS	SET.SOL	SI
Spavinaw			TKN-NH3				
05/13/02							
05/16/02							
05/20/02							
05/22/02	0.640	0.63	0.52	0.00	0.00	0.00	1.37
05/28/02							
06/11/02	0.505	0.62	0.53	0.00	0.00	0.00	1.82
06/17/02							
06/24/02							
07/01/02							
07/08/02							
07/17/02	0.000	0.70	0.59	0.00	0.00	0.00	1.55
07/22/02							
07/29/04							
08/06/02							
08/12/02							
08/15/02	0.041	0.22	0.18	0.00	0.00	0.00	2.73
08/19/02							
08/26/02							
09/03/02							
09/09/02							
09/18/02	0.000	0.35	0.26	0.00	0.00	0.00	3.25
09/23/02							
09/30/02							
10/07/02							
10/15/02	0.000	0.60	0.41	0.00	0.00	0.00	3.73
10/30/02	0.000	0.00	0.00	0.00	0.00	0.00	0.00
11/04/02							
11/13/02	0.089	0.44	0.395	0.00	0.00	0.00	2.50
11/18/02							
11/25/02							
12/02/02	0.095	0.33	0.17	0.00	0.00	0.00	1.67
12/11/02	0.088	0.31	0.27	0.00	0.00	0.00	1.36
12/16/02	0.084	0.39	0.00	0.00	0.00	0.00	0.48
12/26/02							
01/02/03							
01/06/03							
01/13/03							
01/21/03							
01/27/03							
02/05/03	0.079	0.36	0.30	0.00	0.00	0.00	0.22
03/06/03	0.080	0.36	0.31	0.00	0.00	0.00	0.07
04/10/03	0.053	0.39	0.26	0.00	0.00	0.00	0.52
05/07/03	0.075	0.00	0.00	0.00	0.00	0.00	0.18

Lake	SULFATE	TURB	REDOX(Mv)	chlorA	Geosmin	Day
Spavinaw					ng/L	Length hrs
				EXTR.		Lat.35N
01/14/99	5.80	2.47	438.13	11.07		9.86
02/10/99	6.48	6.03	476.38	7.17		10.57
03/11/99	7.15	4.85	442.13	18.08		11.55
04/20/99	0.00	4.42	436.00	14.65		13.03
04/29/99	0.00	3.88	451.38	11.26		13.33
05/12/99	0.00	4.35	427.25	0.00		13.72
05/26/99	7.50	6.58	393.25	34.39		14.07
06/10/99	0.00	9.01	343.50	35.37		14.28
06/24/99	0.00	2.68	345.13	6.26		14.33
07/15/99	0.00	3.91	215.75	23.97		14.15
07/29/99	0.00	4.08	155.50	25.14		13.83
08/11/99	4.80	3.97	133.25	13.29		13.46
08/26/99	0.00	3.04	175.13	13.24	3.9	12.94
09/16/99	0.00	3.92	223.50	17.48	0.0	12.16
09/29/99	0.00	3.27	353.63	14.37	1.6	11.68
10/12/99	0.00	2.10	361.88	11.02	2.1	11.24
11/04/99	3.93	6.05	472.25	8.35	0.0	10.44
12/07/99	0.00	6.33	466.13	9.03	0.0	9.68
01/19/00	0.00	5.39	440.00	13.19	14.0	9.97
02/09/00	5.25	2.89	412.13	9.88	20.0	10.54
03/07/00	0.00	3.46	426.25	12.34	7.5	11.40
04/13/00	0.00	3.39	437.13	11.20	26.5	12.77
04/26/00	0.00	1.89	368.63	6.70	9.9	13.23
05/11/00	0.00	3.05	441.75	10.00	10.0	13.69
06/13/00	0.00	4.31	231.75	24.10	6.9	14.31
06/29/00	0.00	3.81	192.00	24.40	0.0	14.33
07/13/00	0.00	5.61	155.00	32.90	3.5	14.18
07/27/00	0.00	4.50	161.25	20.20	4.6	13.88
08/10/00	0.00	3.19	148.13	10.80	3.0	13.49
08/24/00	0.00	2.89	225.25	11.70	4.1	13.01
08/28/00					2.9	13.03
09/05/00					2.1	12.86
09/14/00	4.15	3.97	153.25	6.50	1.7	12.24
09/28/00	0.00	3.71	180.50	12.30	5.0	11.94
10/02/00					30.0	11.85
10/17/00	0.00	3.46	243.75	11.80	31.0	11.07
10/24/00					100.0	10.97
10/30/00					120.0	10.84
11/07/00					220.0	10.69
11/16/00	2.98	6.64	425.36	6.80	130.0	10.13
11/20/00					210.0	10.07
11/28/00					1200.0	9.96
11/29/00					660.0	9.95
11/30/00					1700.0	9.93

Lake Spavinaw	SULFATE	TURB	REDOX(Mv)	chlorA EXTR.	Geosmin ng/L	Day Length hrs Lat.35N
12/05/00					1300.0	9.89
12/11/00					1800.0	9.85
12/18/00					1400.0	9.82
12/20/00					2600.0	9.82
01/03/01					1200.0	9.86
01/08/01					950.0	9.91
01/10/01					940.0	9.92
01/17/01					420.0	10.00
01/23/01	0.00	2.94	383.13	5.50	150.0	10.09
01/24/01					80.0	10.12
01/29/04					52.0	10.20
01/31/01					40.0	10.23
02/05/01					30.0	10.32
02/07/01					31.0	10.36
02/14/01					37.0	10.90
02/22/01	0.00	4.18	500.38	7.50	15.0	10.94
02/28/01					16.0	11.67
03/07/01					8.9	11.80
03/13/01	0.00	12.53	488.13	20.00	6.5	11.93
04/11/01					4.2	13.00
04/16/01	5.68	2.68	377.88	0.00	4.7	13.01
04/25/01					4.0	13.69
05/02/01					7.5	13.83
05/09/01	0.00	1.67	398.63	20.00	13.0	13.96
05/21/01					10.0	14.15
05/30/01					1.3	14.25
06/06/01					5.5	14.28
06/13/01					4.4	14.36
06/20/01	0.00	4.59	250.50	37.00	1.6	14.33
06/27/01					3.4	14.36
07/02/01					1.8	
07/10/01	0.00	5.81	141.75	9.60	3.8	14.22
07/18/01					3.0	
07/25/01					3.2	
08/01/01					3.1	
08/08/01					2.5	
08/14/01	4.95	3.79	221.50	12.20	3.3	13.37
08/22/01					3.8	
08/29/01					5.2	
09/05/01					5.3	
09/11/01	0.00	3.52	282.75	21.20	12.1	12.35
09/19/01					12.0	
09/26/01					26.5	
10/02/01					11.3	

Lake	SULFATE	TURB	REDOX(Mv)	chlorA	Geosmin	Day
Spavinaw					ng/L	Length hrs
				EXTR.		Lat.35N
10/10/01					17.4	
10/17/01	0.00	5.27	376.25	9.70	21.8	11.07
10/23/01					85.7	
10/31/01					112.0	
11/05/01					103.0	
11/07/01					240.0	
11/14/01	0.00	4.86	378.50	14.00	165.0	10.17
11/19/01					124.0	
11/26/01					340.0	
11/28/01					1010.0	
12/03/01					137.0	
12/05/01					155.0	
12/10/01					2240.0	
12/13/01	0.00	7.41	470.13	10.70	1230.0	9.56
12/16/01					477.0	
12/19/01					595.0	
12/26/01					991.0	
01/02/02					1710.0	
01/07/02					423.0	
01/09/02					670.0	
01/14/02					1290.0	
01/17/02	0.00	6.05	443.29	0.00	1890.0	9.92
01/23/02					1100.0	
01/28/02					717.0	
01/30/02					810.0	
02/04/02					306.0	
02/06/02					400.0	
02/11/02					87.3	
02/14/02	0.00	4.66	390.50	0.00	49.0	10.69
02/18/02					26.0	
02/20/02					14.7	
02/25/02					9.4	
02/27/02					6.9	
03/05/02					7.3	
03/11/02					5.4	
03/14/02	0.00	4.18	407.88	0.00	5.0	11.67
03/18/02					3.4	
03/25/02					2.0	
04/01/02					4.4	
04/08/02					4.9	
04/17/02	0.00	1.40	453.63	0.00	4.7	12.92
04/22/02					13.1	
04/29/02					23.1	
05/06/02					16.0	

Lake	SULFATE	TURB	REDOX (Mv)	chlorA	Geosmin	Day
Spavinaw					ng/L	Length hrs
				EXTR.		Lat.35N
05/13/02					43.0	
05/16/02					57.3	
05/20/02					42.8	
05/22/02	0.00	3.18	0.00	6.61	138.0	13.98
05/28/02					13.1	
06/11/02	0.00	3.33	0.00	7.06	4.6	14.29
06/17/02					7.2	
06/24/02					7.2	
07/01/02					7.9	
07/08/02					5.7	
07/17/02	0.00	2.93	0.00	17.33	6.4	14.12
07/22/02					3.2	
07/29/04					4.2	
08/06/02					2.4	
08/12/02					2.8	
08/15/02	0.00	3.07	0.00	2.51	2.8	13.34
08/19/02					3.0	
08/26/02					18.0	
09/03/02					5.2	
09/09/02					0.0	
09/18/02	0.00	2.97	0.00	0.00	4.9	12.09
09/23/02					4.5	
09/30/02					5.0	
10/07/02					5.1	
10/15/02	0.00	3.84	0.00	2.60	2.6	11.14
10/30/02	0.00	3.63	0.00	4.79	2.9	10.56
11/04/02					3.2	
11/13/02	0.00	4.10	0.00	7.34	5.1	10.20
11/18/02					6.6	
11/25/02					9.0	
12/02/02	0.00	4.27	0.00	7.66	15.3	9.79
12/11/02	0.00	3.81	0.00	7.65	14.5	9.60
12/16/02	0.00	4.24	0.00	10.51	16.8	9.50
12/26/02					29.9	
01/02/03					20.0	
01/06/03					21.0	
01/13/03					27.3	
01/21/03					21.6	
01/27/03					19.6	
02/05/03	0.00	2.72	0.00	7.69	17.6	10.42
03/06/03	0.00	3.40	0.00	8.11	6.7	11.37
04/10/03	0.00	3.58	0.00	1.35		12.66
05/07/03	0.00	1.19	0.00	0.64		13.58

Lake	STATION	^{0}C	TEMP ^{0}C	SAT	D.O.	pH	COND
Eucha		AIRTEMP		D.O.			
Date				%	(ppm)		$_m$mhos/cm
1/12/99	EUC01-6	10.6	5.2	92.9	11.8	8.13	221
2/17/99	EUC01-6	7.0	9.0	88.2	10.2	7.82	218
3/10/99	EUC01-6	7.4	9.1	100.0	11.5	8.35	227
4/13/99	EUC01-6	14.5	15.8	100.5	9.9	8.49	209
4/28/99	EUC01-6	14.1	15.4	87.0	8.7	8.00	226
5/13/99	EUC01-6	17.6	17.9	84.2	8.0	8.03	207
6/9/99	EUC01-6	27.2	23.6	89.0	7.0	8.33	185
6/28/99	EUC01-6	26.1	23.4	0.0	4.5	7.64	194
7/13/99	EUC01-6	24.4	22.7	61.9	5.1	7.96	190
7/27/99	EUC01-6	30.6	23.4	62.0	4.6	7.99	168
8/10/99	EUC01-6	32.2	26.3	72.6	5.5	8.16	174
8/24/99	EUC01-6	26.7	24.5	65.3	5.1	7.82	191
9/15/99	EUC01-6	17.0	23.3	63.3	5.3	7.95	189
9/30/99	EUC01-6	11.7	20.1	54.7	4.9	7.61	196
10/13/99	EUC01-6	14.7	20.2	6.7	6.7	8.07	207
11/3/99	EUC01-6	4.2	15.7	6.6	0.7	7.16	227
1/18/00	EUC01-6	5.7	7.6	82.0	9.8	8.04	235
2/8/00	EUC01-6	1.9	5.4	89.1	10.3	8.18	233
3/9/00	EUC01-6	10.8	11.3	89.9	9.8	7.88	244
4/12/00	EUC01-6	9.9	13.9	98.3	10.1	8.07	244
4/27/00	EUC01-6	17.2	16.5	101.0	9.8	8.20	260
5/10/00	EUC01-6	17.1	19.5	88.4	8.1	8.25	238
5/24/00	EUC01-6	25.6	22.2	95.2	8.2	8.29	237
6/15/00	EUC01-6	24.4	23.0	54.1	4.4	7.77	203
6/27/00	EUC01-6	26.5	21.9	71.0	6.0	7.88	206
7/11/00	EUC01-6	31.4	24.2	69.5	5.3	7.98	193
7/25/00	EUC01-6	20.7	23.7	56.2	4.4	8.07	184
8/8/00	EUC01-6	30.1	25.1	75.2	5.7	8.25	171
8/22/00	EUC01-6	27.0	25.0	67.0	5.1	8.10	185
8/28/00							
9/5/00							
9/13/00	EUC01-6	23.7	24.4	56.9	4.5	8.11	180
9/18/00							
9/26/00	EUC01-6	12.5	20.0	29.0	2.6	7.28	206
10/2/00							
10/9/00							
10/18/00	EUC01-6	14.4	17.9	73.5	7.0	7.79	211
10/24/00							
10/30/00							
11/7/00							
11/15/00	EUC01-6	8.5	13.6	33.7	3.5	7.43	209
11/20/00							
11/28/00							
11/29/00							

Lake Eucha Date	STATION	AIRTEMP ^0C	TEMP ^0C	SAT D.O. %	D.O. (ppm)	pH	COND $_m$mhos/cm
1/8/01							
1/17/01							
1/22/01							
1/24/01							
1/31/01	EUC01-6	4.4	3.8	89.4	11.8	8.13	225
2/5/01							
2/7/01							
2/14/01							
2/20/01	EUC01-6	6.7	5.9	95.3	11.9	8.46	217
2/28/01							
3/7/01							
3/14/01	EUC01-6	11.3	8.9	76.8	8.9	7.56	197
4/10/01	EUC01-6	21.4	15.5	122.4	12.1	8.63	200
4/18/01							
4/25/01							
5/2/01							
5/10/01	EUC01-6	21.4	20.5	113.9	10.1	8.51	179
5/21/01							
5/30/01							
6/6/01							
6/14/01	EUC01-6	28.9	25.0	93.3	7.3	8.55	172
6/20/01							
6/27/01							
7/2/01							
7/11/01	EUC01-6	25.5	26.5	66.6	4.9	8.18	166
7/18/01							
7/25/01							
8/1/01							
8/8/01							
8/15/01	EUC01-6	23.4	26.2	60.0	4.5	8.43	178
8/22/01							
8/29/01							
9/5/01							
9/12/01	EUC01-6	17.9	25.7	102.7	8.4	8.56	175
9/19/01							
9/26/01							
10/2/01							
10/10/01							
10/16/01	EUC01-6	4.0	17.5	48.6	4.7	7.52	204
10/23/01							
10/31/01							
11/5/01							
11/7/01							
11/13/01	EUC01-6	15.4	15.8	64.0	6.3	7.50	231

Lake Eucha Date	STATION	^{0}C AIRTEMP	TEMP ^{0}C	SAT D.O. %	D.O. (ppm)	pH	COND $_m$mhos/cm
12/3/01							
12/10/01							
12/11/01	EUC01-6	4.0	11.0	66.6	7.3	8.03	248
12/17/01							
12/19/01							
12/26/01							
1/2/02							
1/7/02							
1/9/02							
1/14/02							
1/16/02	EUC01-6	9.0	5.7	100.1	12.5	8.60	240
1/28/02							
1/30/02							
2/4/02							
2/6/02							
2/11/02							
2/13/02	EUC01-6	1.9	5.7	103.3	12.9	8.47	103
2/18/02							
2/20/02							
2/25/02							
2/27/02							
3/5/02							
3/13/02	EUC01-6	9.0	7.0	87.9	10.7	7.86	239
3/18/02							
3/25/02							
4/1/02							
4/8/02							
4/16/02	EUC01-6	22.0	17.2	105.6	10.2	8.29	248
4/22/02							
4/29/02							
5/6/02							
5/13/02							
5/21/02	EUC01-6	15.5	19.8	119.8	10.9	8.62	234
5/28/02							
6/12/02	EUC01-6	0.0	24.9	88.1	7.1	8.30	205
6/17/02							
6/24/02							
7/1/02							
7/8/02							
7/16/02	EUC01-6	26.0	28.1	10.0	130.2	8.42	189
7/22/02							
7/29/02							
8/6/02							
8/14/02	EUC01-6	19.0	27.1	116.7	9.2	8.26	178

Lake Eucha Date	STATION	^0C AIRTEMP	TEMP ^0C	SAT D.O. %	D.O. (ppm)	pH	COND $_m$mhos/cm
8/19/02							
8/26/02							
9/3/02							
9/9/02							
9/17/02	EUC01-6	22.0	25.8	93.5	7.6	8.30	167
9/23/02							
9/30/02							
10/7/02							
10/14/02							
10/17/02	EUC01-6	3.5	17.7	42.9	4.1	7.67	200
10/30/02	EUC01-6	13.0	15.3	0.0	0.0	7.35	207
11/4/02							
11/14/02	EUC01-6	12.0	12.8	47.7	5.0	7.06	224
11/18/02							
11/25/02							
12/2/02	EUC01-6	8.5	9.7	75.9	8.6	7.38	228
12/10/02	EUC01-6	4.0	8.3	80.5	9.5	7.37	228
12/16/02							
12/26/02							
1/2/03							
1/8/03	EUC01-6	4.5	6.7	92.8	11.4	7.88	231
1/13/03							
1/21/03							
1/27/03							
2/4/03	EUC01-6	-0.5	5.3	98.0	12.4	7.45	238
2/10/03							
2/18/03							
3/3/03							
3/11/03	EUC01-6	2.0	5.9	92.6	11.6	7.58	242

Lake Eucha Date	ALK mg/l	T-PO4 mg/l	D-PO4 mg/l	T.HARD mg/l	NH3 mg/l	NO3 mg/l	NO2 mg/l
1/12/99	93.8	0.012		102.6		1.016	
2/17/99	92.2	0.041	0.018	102.6	0.49	1.692	0.042
3/10/99	93.8	0.021		102.8		1.484	0.031
4/13/99	84.2	0.013	0.010	95.4	0.00	1.864	0.000
4/28/99	87.6	0.012	0.000	96.6	0.09	1.344	0.000
5/13/99	84.6	0.052	0.026	90.8	0.12	1.618	0.000
6/9/99	59.8	0.025	0.017	65.8	0.14	0.952	0.073
6/28/99	77.4	0.008	0.000	81.6	0.33	0.997	0.137
7/13/99	71.6	0.053	0.047	74.8	0.30	0.893	0.051
7/27/99	63.4	0.026	0.036	64.4	0.10	0.788	0.040
8/10/99	64.8	0.038	0.043	66.0	0.21	0.553	0.039
8/24/99	72.2	0.036	0.040	73.8	0.28	0.450	0.000
9/15/99	77.6	0.029	0.034	75.8	0.22	0.170	0.000
9/30/99	90.0	0.017	0.008	87.8	0.39	0.134	0.000
10/13/99	94.2	0.037	0.091	93.8	0.66	0.206	0.000
11/3/99	99.8	0.054	0.022	98.3	0.72	0.157	0.000
1/18/00	102.5	0.029	0.006	110.8	0.07	0.552	0.000
2/8/00	103.8	0.022	0.000	112.2	0.32	0.551	0.000
3/9/00	103.6	0.014	0.000	111.8	0.00	0.616	0.000
4/12/00	105.6	0.007	0.000	110.0	0.00	0.627	0.000
4/27/00	104.6	0.010	0.000	109.8	0.00	0.563	0.000
5/10/00	103.4	0.007	0.031	105.6	0.00	0.507	0.000
5/24/00	97.8	0.031	0.006	98.2	0.00	0.440	0.000
6/15/00	82.8	0.022	0.000	82.2	0.10	0.173	0.082
6/27/00	87.2	0.037	0.005	86.0	0.17	0.446	0.032
7/11/00	71.2	0.044	0.000	73.4	0.24	0.570	0.139
7/25/00	71.6	0.031	0.000	72.2	0.28	0.377	0.000
8/8/00	67.4	0.028	0.006	67.0	0.30	0.221	0.000
8/22/00	66.4	0.027	0.013	68.8	0.14	0.099	0.007
8/28/00							
9/5/00							
9/13/00	74.0	0.032	0.049	71.0	0.24	0.000	0.000
9/18/00							
9/26/00	89.8	0.045	0.020	86.6	0.41	0.064	0.017
10/2/00							
10/9/00							
10/18/00	92.8	0.041	0.014	90.6	0.23	0.071	0.000
10/24/00							
10/30/00							
11/7/00							
11/15/00	98.8	0.060	0.038	98.4	0.54	0.208	0.015
11/20/00							
11/28/00							
11/29/00							

Lake Eucha Date	ALK mg/l	T-PO4 mg/l	D-PO4 mg/l	T.HARD mg/l	NH3 mg/l	NO3 mg/l	NO2 mg/l
1/8/01							
1/17/01							
1/22/01							
1/24/01							
1/31/01	106.0	0.022	0.000	106.4	0.09	0.772	0.010
2/5/01							
2/7/01							
2/14/01							
2/20/01	101.6	0.021	0.000	106.4	0.00	1.342	0.024
2/28/01							
3/7/01							
3/14/01	74.0	0.123	0.102	80.6	0.11	2.880	0.000
4/10/01	73.6	0.048	0.047	87.6	0.06	2.460	0.000
4/18/01							
4/25/01							
5/2/01							
5/10/01	72.4	0.013	0.016	82.0	0.06	2.120	0.048
5/21/01							
5/30/01							
6/6/01							
6/14/01	54.4	0.011	0.000	60.0	0.00	1.164	0.029
6/20/01							
6/27/01							
7/2/01							
7/11/01	55.4	0.020	0.000	57.0	0.22	0.426	0.041
7/18/01							
7/25/01							
8/1/01							
8/8/01							
8/15/01	64.2	0.022	0.000	63.8	0.21	0.630	0.000
8/22/01							
8/29/01							
9/5/01							
9/12/01	68.0	0.021	0.000	67.2	0.00	0.630	0.000
9/19/01							
9/26/01							
10/2/01							
10/10/01							
10/16/01	88.7	0.025	0.000	81.5	0.30	0.190	0.000
10/23/01							
10/31/01							
11/5/01							
11/7/01							
11/13/01	89.0	0.020	0.000	91.4	0.36	0.174	0.000

Lake Eucha Date	ALK mg/l	T-PO4 mg/l	D-PO4 mg/l	T.HARD mg/l	NH3 mg/l	NO3 mg/l	NO2 mg/l
12/3/01							
12/10/01							
12/11/01	102.3	0.022	0.000	99.3	0.44	0.288	0.000
12/17/01							
12/19/01							
12/26/01							
1/2/02							
1/7/02							
1/9/02							
1/14/02							
1/16/02	105.0	0.025	0.000	109.8	0.07	0.755	0.000
1/28/02							
1/30/02							
2/4/02							
2/6/02							
2/11/02							
2/13/02	96.0	0.017	0.000	104.2	0.00	0.845	0.000
2/18/02							
2/20/02							
2/25/02							
2/27/02							
3/5/02							
3/13/02	100.0	0.017	0.000	105.2	0.04	0.966	0.000
3/18/02							
3/25/02							
4/1/02							
4/8/02							
4/16/02	103.8	0.017	0.000	107.8	0.00	1.253	0.000
4/22/02							
4/29/02							
5/6/02							
5/13/02							
5/21/02	99.8	0.018	0.000	102.6	0.00	1.109	0.000
5/28/02							
6/12/02	72.0	0.017	0.000	81.7	0.00	0.924	0.000
6/17/02							
6/24/02							
7/1/02							
7/8/02							
7/16/02	73.3	0.016	0.000	75.7	0.15	0.623	0.000
7/22/02							
7/29/02							
8/6/02							
8/14/02	67.3	0.020	0.000	68.3	0.06	0.162	0.000

Lake Eucha Date	ALK mg/l	T-PO4 mg/l	D-PO4 mg/l	T.HARD mg/l	NH3 mg/l	NO3 mg/l	NO2 mg/l
8/19/02							
8/26/02							
9/3/02							
9/9/02							
9/17/02	69.0	0.031	0.000	67.7	0.04	0.162	0.000
9/23/02							
9/30/02							
10/7/02							
10/14/02							
10/17/02	79.3	0.016	0.000	76.1	0.04	0.162	0.000
10/30/02	87.0	0.016	0.000	83.2	0.00	0.162	0.000
11/4/02							
11/14/02	98.5	0.024	0.000	92.6	0.61	0.067	0.000
11/18/02							
11/25/02							
12/2/02	100.0	0.014	0.000	95.7	0.54	0.115	0.000
12/10/02	98.5	0.019	0.000	95.3	0.69	0.121	0.000
12/16/02							
12/26/02							
1/2/03							
1/8/03	100.5	0.019	0.000	102.0	0.26	0.200	0.000
1/13/03							
1/21/03							
1/27/03							
2/4/03	104.8	0.018	0.000	101.8	0.16	0.283	0.013
2/10/03							
2/18/03							
3/3/03							
3/11/03	105.5	0.016	0.000	104.2	0.09	0.339	0.027

Lake	NO2+NO3	TKN	Organic N	TDS	TSS	SET.SOL	SI
Eucha			TKN-NH3				
Date	mg/l	mg/l		mg/l	mg/l	mg/l	mg/l
1/12/99	1.023	0.00		138.80	6.84		
2/17/99	1.734	0.53	0.04	137.80	4.40		1.44
3/10/99	1.512	0.44		147.00	5.84		
4/13/99	1.870	0.00	0.00	145.20	0.00	0.00	0.00
4/28/99	1.358	0.31	0.22	130.40	0.00	0.00	0.85
5/13/99	1.644	0.00	0.00	144.20	0.00	0.00	1.72
6/9/99	0.984	1.16	1.03	99.50	0.00	0.00	2.02
6/28/99	1.065	0.40	0.07	133.60	0.00	0.00	3.16
7/13/99	0.814	1.20	0.90	84.60	0.00	0.00	4.88
7/27/99	0.817	0.64	0.55	181.20	0.00	0.00	4.12
8/10/99	0.575	1.86	1.66	98.86	0.00	0.00	3.60
8/24/99	0.475	0.64	0.37	111.20	0.00	0.00	4.06
9/15/99	0.181	1.07	0.85	144.60	0.00	0.00	4.92
9/30/99	0.136	0.63	0.24	138.20	0.00	0.00	4.96
10/13/99	0.226	0.93	0.27	116.60	0.00	0.00	5.20
11/3/99	0.158	1.14	0.42	146.50	0.00	0.00	1.10
1/18/00	0.555	0.41	0.34	134.67	0.00	0.00	1.67
2/8/00	0.551	0.00	0.00	123.80	0.00	0.00	1.22
3/9/00	0.617	0.46	0.46	88.80	0.00	0.00	1.10
4/12/00	0.627	0.40	0.40	145.40	0.00	0.00	0.61
4/27/00	0.568	0.45	0.45	122.00	0.00	0.00	0.60
5/10/00	0.508	0.32	0.32	146.60	0.00	0.00	1.07
5/24/00	0.451	1.30	1.30	0.00	0.00	0.00	1.82
6/15/00	0.208	0.46	0.36	103.80	0.00	0.00	1.68
6/27/00	0.464	0.56	0.39	116.20	0.00	0.00	3.12
7/11/00	0.637	0.82	0.58	102.68	0.00	0.00	3.26
7/25/00	0.396	0.69	0.42	130.36	0.00	0.00	3.56
8/8/00	0.241	0.58	0.29	109.60	0.00	0.00	3.80
8/22/00	0.109	0.69	0.55	162.40	0.00	0.00	4.02
8/28/00							
9/5/00							
9/13/00	0.000	0.77	0.53	121.40	0.00	0.00	4.68
9/18/00							
9/26/00	0.071	0.72	0.31	164.80	0.00	0.00	5.18
10/2/00							
10/9/00							
10/18/00	0.071	0.66	0.43	161.80	0.00	0.00	4.72
10/24/00							
10/30/00							
11/7/00							
11/15/00	0.220	1.01	0.47	139.00	0.00	0.00	4.40
11/20/00							
11/28/00							

11/29/00							
Lake Eucha Date	NO2+NO3 mg/l	TKN mg/l	Organic N TKN-NH3	TDS mg/l	TSS mg/l	SET.SOL mg/l	SI mg/l
1/8/01							
1/17/01							
1/22/01							
1/24/01							
1/31/01	0.776	0.36	0.27	140.20	0.00	0.00	2.20
2/5/01							
2/7/01							
2/14/01							
2/20/01	1.380	0.31	0.31	127.20	0.00	0.00	1.90
2/28/01							
3/7/01							
3/14/01	2.920	0.64	0.53	122.20	0.00	0.00	5.47
4/10/01	2.480	0.41	0.35	113.90	0.00	0.00	2.31
4/18/01							
4/25/01							
5/2/01							
5/10/01	2.160	1.05	0.99	121.60	0.00	0.00	2.89
5/21/01							
5/30/01							
6/6/01							
6/14/01	1.204	0.51	0.51	100.20	0.00	0.00	1.29
6/20/01							
6/27/01							
7/2/01							
7/11/01	0.446	0.78	0.56	130.12	0.00	0.00	1.99
7/18/01							
7/25/01							
8/1/01							
8/8/01							
8/15/01	0.630	0.71	0.50	94.86	0.00	0.00	2.38
8/22/01							
8/29/01							
9/5/01							
9/12/01	0.329	0.41	0.41	98.53	0.00	0.00	2.57
9/19/01							
9/26/01							
10/2/01							
10/10/01							
10/16/01	0.114	0.63	0.33	113.88	0.00	0.00	2.83
10/23/01							
10/31/01							
11/5/01							
11/7/01							
11/13/01	0.156	0.75	0.39	122.47	0.00	0.00	2.78

Lake Eucha Date	NO2+NO3 mg/l	TKN mg/l	Organic N TKN-NH3	TDS mg/l	TSS mg/l	SET.SOL mg/l	SI mg/l
12/3/01							
12/10/01							
12/11/01	0.291	0.90	0.46	157.37	0.00	0.00	3.08
12/17/01							
12/19/01							
12/26/01							
1/2/02							
1/7/02							
1/9/02							
1/14/02							
1/16/02	0.770	0.57	0.50	0.00	0.00	0.00	1.14
1/28/02							
1/30/02							
2/4/02							
2/6/02							
2/11/02							
2/13/02	0.852	0.37	0.37	0.00	0.00	0.00	1.14
2/18/02							
2/20/02							
2/25/02							
2/27/02							
3/5/02							
3/13/02	0.968	0.50	0.46	0.00	0.00	0.00	1.14
3/18/02							
3/25/02							
4/1/02							
4/8/02							
4/16/02	1.254	0.37	0.37	0.00	0.00	0.00	0.68
4/22/02							
4/29/02							
5/6/02							
5/13/02							
5/21/02	1.125	0.45	0.45	0.00	0.00	0.00	0.97
5/28/02							
6/12/02	0.947	0.65	0.65	0.00	0.00	0.00	1.62
6/17/02							
6/24/02							
7/1/02							
7/8/02							
7/16/02	0.647	0.51	0.36	0.00	0.00	0.00	1.57
7/22/02							
7/29/02							
8/6/02							
8/14/02	0.172	0.47	0.41	0.00	0.00	0.00	1.54

Lake Eucha Date	NO2+NO3 mg/l	TKN mg/l	Organic N TKN-NH3	TDS mg/l	TSS mg/l	SET.SOL mg/l	SI mg/l
8/19/02							
8/26/02							
9/3/02							
9/9/02							
9/17/02	0.172	0.66	0.62	0.00	0.00	0.00	1.09
9/23/02							
9/30/02							
10/7/02							
10/14/02							
10/17/02	0.172	0.48	0.44	0.00	0.00	0.00	0.62
10/30/02	0.172	0.48	0.48	0.00	0.00	0.00	0.62
11/4/02							
11/14/02	0.069	0.80	0.20	0.00	0.00	0.00	1.71
11/18/02							
11/25/02							
12/2/02	0.118	0.63	0.10	0.00	0.00	0.00	1.41
12/10/02	0.130	0.65	0.00	0.00	0.00	0.00	1.16
12/16/02							
12/26/02							
1/2/03							
1/8/03	0.200	0.83	0.57	0.00	0.00	0.00	0.39
1/13/03							
1/21/03							
1/27/03							
2/4/03	0.288	0.64	0.48	0.00	0.00	0.00	0.21
2/10/03							
2/18/03							
3/3/03							
3/11/03	0.348	0.54	0.46	0.00	0.00	0.00	0.07

Lake Eucha Date	SULFATE mg/l	TURB NTU	REDOX(Mv)	chlor A	Geosmin	Day Length hrs Lat.35N
1/12/99	5.84	2.46	457.64			9.89
2/17/99	6.54	7.50	471.09			10.73
3/10/99	6.28	3.99	456.00			11.74
4/13/99	0.00	1.50	445.55			12.89
4/28/99	0.00	2.96	454.91			13.4
5/13/99	0.00	3.12	435.18			13.84
6/9/99	0.00	11.97	365.64			14.34
6/28/99	0.00	1.97	406.45			14.33
7/13/99	0.00	10.63	355.09			14.14
7/27/99	0.00	3.88	273.82			13.77
8/10/99	4.86	4.83	220.09			13.32
8/24/99	0.00	5.16	185.64		4.50	12.77
9/15/99	0.00	3.10	179.91			12.21
9/30/99	0.00	2.86	304.82			11.65
10/13/99	0.00	2.29	291.82			11.1
11/3/99	3.80	3.83	329.00			10.56
1/18/00	0.00	3.23	455.75		19.00	9.82
2/8/00	5.38	2.27	442.09		31.00	10.51
3/9/00	0.00	2.01	461.00		36.00	11.48
4/12/00	0.00	1.63	453.82		36.00	12.73
4/27/00	0.00	0.85	420.55		19.00	13.26
5/10/00	0.00	1.23	403.09		9.00	13.66
5/24/00	4.66	1.69	348.27		6.80	14.02
6/15/00	0.00	2.36	379.36		14.00	14.33
6/27/00	0.00	6.34	261.73		0.00	14.33
7/11/00	0.00	4.15	85.73		4.20	14.2
7/25/00	0.00	4.51	97.91		3.70	13.92
8/8/00	0.00	4.44	66.82		3.60	13.55
8/22/00	0.00	5.46	0.09	17.60	4.4	13.09
8/28/00					3.8	
9/5/00					2.5	
9/13/00	5.42	6.45	72.27	5.00	1.6	12.27
9/18/00					1.3	
9/26/00	0.00	3.75	115.64		1.7	11.79
10/2/00					6.3	
10/9/00					6.4	
10/18/00	0.00	2.31	280.18	22.70	3.7	11.04
10/24/00					8.8	
10/30/00					7.2	
11/7/00					8.7	
11/15/00	0.00	2.73	388.36	5.00	6.2	10.14
11/20/00					6.1	
11/28/00					7.4	
11/29/00					7.8	

Lake Eucha Date	SULFATE mg/l	TURB NTU	REDOX (Mv)	chlor A	Geosmin	Day Length hrs Lat.35N
1/8/01					31	
1/17/01					22	
1/22/01					20	
1/24/01					23	
1/31/01	0.00	2.88	437.55		34	10.27
2/5/01					30	
2/7/01					25	
2/14/01					26	
2/20/01	0.00	2.67	448.18	9.80	19	10.87
2/28/01					8.4	
3/7/01					6.9	
3/14/01	0.00	27.38	422.45		6.7	11.67
4/10/01	5.88	7.48	334.91		4.9	12.66
4/18/01					3.2	
4/25/01					4.9	
5/2/01					6.8	
5/10/01	0.00	2.20	430.45		15	13.66
5/21/01					39	
5/30/01					12	
6/6/01					43	
6/14/01	0.00	2.99	355.55		51	14.32
6/20/01					49.6	
6/27/01					21.8	
7/2/01					5.8	
7/11/01	0.00	3.12	314.45	17.10	7.04	14.2
7/18/01					5	
7/25/01					5.65	
8/1/01					7.7	
8/8/01					2.75	
8/15/01	4.96	3.13	283.27	9.80	11.6	13.34
8/22/01					9.48	
8/29/01					12.1	
9/5/01					12.1	
9/12/01	4.96	2.75	230.50		13.9	12.31
9/19/01					13.5	
9/26/01					9.14	
10/2/01					17.7	
10/10/01					14.3	
10/16/01	4.96	2.96	377.13	7.30	12.5	11.11
10/23/01					47.7	
10/31/01					51.3	
11/5/01					56.6	
11/7/01					38.8	

Lake Eucha Date	SULFATE mg/l	TURB NTU	REDOX (Mv)	chlor A	Geosmin	Day Length hrs Lat.35N
11/13/01	4.96	2.70	368.63	15.10	52.7	10.2
12/3/01					110	
12/10/01					114	
12/11/01	4.96	3.85	455.00		103	9.58
12/17/01					31.6	
12/19/01					36.8	
12/26/01					92.7	
1/2/02					209	
1/7/02					150	
1/9/02					140	
1/14/02					167	
1/16/02	0.00	4.69	399.75	38.70	232	9.89
1/28/02					137	
1/30/02					170	
2/4/02					198	
2/6/02					410	
2/11/02					212	
2/13/02	0.00	3.03	402.75	14.10	140	10.66
2/18/02					210	
2/20/02					85.1	
2/25/02					110	
2/27/02					101	
3/5/02					65.8	
3/13/02	0.00	2.84	391.88	6.40	28.5	11.63
3/18/02					7	
3/25/02					9.29	
4/1/02					4.94	
4/8/02					6.27	
4/16/02	0.00	2.28	448.13		4.3	12.89
4/22/02					3.56	
4/29/02					1.32	
5/6/02					4.24	
5/13/02					2.26	
5/21/02	0.00	2.11	0.00	5.00	3.55	13.95
5/28/02					2.32	
6/12/02	0.00	2.40	0.00	8.30	19	14.3
6/17/02					8.94	
6/24/02					11.6	
7/1/02					11	
7/8/02					14.6	
7/16/02	0.00	2.32	0.00	5.30	10	14.12
7/22/02					11.8	
7/29/02					6.18	
8/6/02					5.4	

8/14/02	0.00	2.78	0.00		3.69	13.37
Lake Eucha Date	SULFATE mg/l	TURB NTU	REDOX (Mv)	chlor A	Geosmin	Day Length hrs Lat.35N
8/19/02					3.59	
8/26/02					36	
9/3/02					1.3	
9/9/02					12.7	
9/17/02	0.00	3.96	0.00		13	12.12
9/23/02					18	
9/30/02					16.3	
10/7/02					12.8	
10/14/02					8.2	
10/17/02	0.00	3.86	0.00	2.60	12.1	11.07
10/30/02	0.00	2.84	0.00	1.30	4.1	10.59
11/4/02					5.71	
11/14/02	0.00	2.02	0.00	1.10	8.11	10.17
11/18/02					31.4	
11/25/02					17	
12/2/02	0.00	2.76	0.00	3.90	27	9.79
12/10/02	0.00	3.31	0.00	2.60	34.3	9.62
12/16/02					64.9	
12/26/02					140	
1/2/03					58	
1/8/03	0.00	3.23	0.00	2.80	35.8	9.78
1/13/03					68.9	
1/21/03					48.6	
1/27/03					43.3	
2/4/03	0.00	3.02	0.00	19.00	37.7	10.39
2/10/03					25.1	
2/18/03					22.3	
3/3/03					8.01	
3/11/03	0.00	2.70	0.00	12.00	4.49	11.52

VITA

Jeana W. Davis

Candidate for the Degree of

Master of Science

Thesis: CONTRIBUTION OF *Anabaena circinalis* TO GEOSMIN LEVELS IN LAKE SPAVINAW AND LAKE EUCHA

Major Field: Environmental Science

Biographical:

Personal Data: Born in Memphis, Tennessee on January 26, 1957, daughter of George P. and Ann M. Wilson.

Education: Graduated from Trezevant High School, Memphis Tennessee May 1974; received Bachelor of Science degree in Biology from the University of Tennessee in May 1978. Completed the requirements for Master of Science degree with a major in Environmental Science at Oklahoma State University in July 2004.

Experience: Pollution Control Inspector with City of Memphis 1978-1981; Lab Technician with Cargill Corn Milling, Memphis, TN 1981-1983; Lab Analyst Millipore Corp., Bedford MA, 1983-1984; Chemist, Compuchem Inc. Research Triangle Park, NC 1984-1988; Section Leader USPCI-Laidlaw, Tulsa, OK 1988-1997; Metals Section Shift Supervisor, Southwest Laboratory, Broken Arrow, OK 1997-1998; Microbiologist, City of Tulsa, OK, 1998-present.